University of Texas Bulletin

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JOHN T. LONSDALE

Bureau of Economic Geology

J. A. Udden, Direcor E. H. Sellards, Associate Director

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

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THE IGNEOUS ROCKS OF THE BALCONES FAULT REGION OF TEXAS[1]

BY

JOHN T. LONSDALE

INTRODUCTION

The following report relates to the massive and altered igneous rocks, of the Balcones Fault Region of Texas. These rocks which include a series of basaltic and phonolitic masses of which Pilot Knob in Travis County is a well known example, are confined generally to Cretaceous formations and form a group whose logical treatment should be in one paper. Reference to Figure 1, a sketch map, will show the general location of the igneous rocks considered.

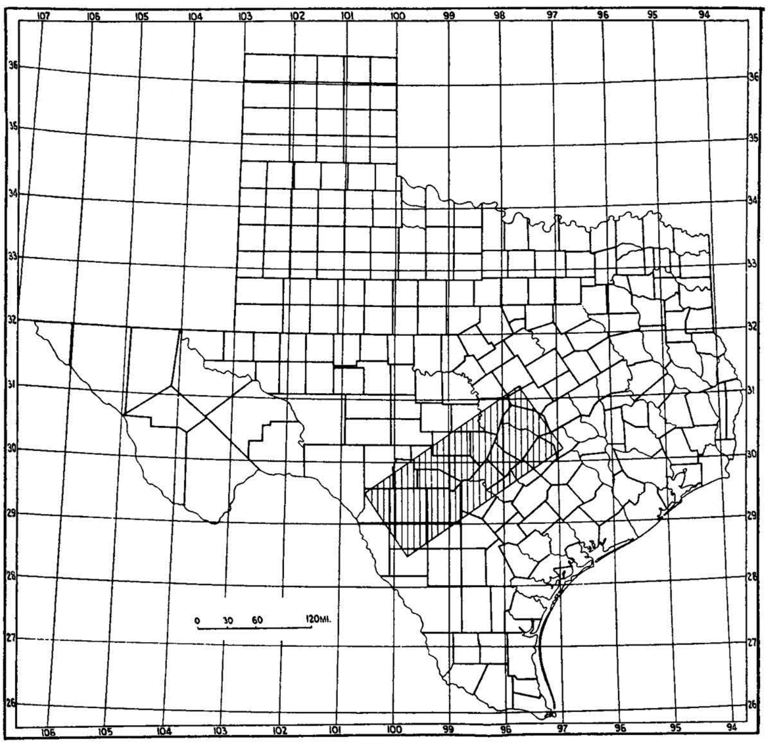

Fig. 1. Index map showing location of igneous rocks to which this report relates.

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[1]Manuscript submitted May, 1927. Publication issued December, 1927.

The report is based on field and laboratory studies made during the years of 1925, 1926, and 1927, supplemented wherever possible by the use of data already published. Since, as will be seen later, previous reports are largely fragmentary or relate to isolated fields, considerable new work is involved. No attempt has been made to map the geologic details of all of the igneous rocks, though certain typical occurrences have been mapped and figured for reference.

Previous Work.—No work of a similar nature has been carried on in this region, although descriptions of isolated igneous bodies have been made from time to time and in the case of the Uvalde Quadrangle the igneous rocks have been described in some detail. Most of the geologic reports covering the area have been made from a stratigraphic viewpoint and make only casual mention of the igneous rocks. A list of the more important references to the literature of the region is given below.

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Osnann, A., Melilite-Nepheline Basalt and Nepheline-Basanite from Southern Texas. Jour. Geol. 1, pp. 341–346, 1893.

Tait, J. L., Report of Geologist for Southern Texas. Texas Geol. Surv. Report, progress 1 (1888), pp. 64–66, 1889.

Udden, J. A., Report on a Geological Survey of the Lands Belonging to the New York and Texas Land Company, Ltd., in the Upper Rio Grande Embayment in Texas. Augustana Library Publications No. 6, pp. 53–107, 1907.

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Vaughan, T. W., U. S. Geol. Surv. Geologic Atlas, Uvalde Folio, No. 64, with petrography described by Whitman Cross, 1900.

Acknowledgments.—The writer is under obligation to a number of people for assistance rendered. To Dr. E. H. Sellards of the Bureau of Economic Geology the writer owes the opportunity for the work and much valuable assistance during the preparation of the report. Mr. Arthur Keith of the United States Geological Survey very generously gave the writer the benefit of his great knowledge of crystalline rocks, especially with reference to the Uvalde district. Professor H. C. George of the University of Oklahoma with whom the writer spent several days in the field gave many helpful suggestions. Dr. E. P. Schoch of the Bureau of Industrial Chemistry, University of Texas, furnished a number of chemical analyses quoted in the report. The petroleum companies furnished data and samples from the various serpentine occurrences, and were generally very generous in this matter. Dr. M. A. Hanna supplied the photograph of the serpentine core shown in the report and along with Messrs. G. Kirby and J. M. Dawson furnished data on the igneous rocks of Bandera County. Dr. Whitman Cross gave a very helpful general criticism of the greater part of the manuscript.

MASSIVE IGNEOUS ROCKS

GEOLOGY OF THE IGNEOUS ROCKS

Location of Igneous Rocks.—The igneous rocks considered here are found in a belt, nearly coincident with the Balcones Fault Zone, extending from Travis County in the northeast to Kinney County in the southwest. The Balcones Fault extends from north of Austin in a curved line southwest to Del Rio. Over much of its trace a prominent escarpment marks the location of the main fault. The fault zone is generally several miles wide and includes faults other than the main Balcones Fault.

The Balcones Fault separates the Edwards Plateau region on the west or northwest from the Coastal Plain, the latter extending from the fault escarpment to the Gulf of Mexico. The Edwards Plateau is a broad undulating topographic unit generally several hundred feet above the Coastal Plain, the separating escarpment being much more prominent in some localities than in others. A few of the bodies of igneous rock described in this report are located on the Edwards Plateau. The greater number, however, are on the downthrown or Coastal Plain side and in the zone affected by faulting.

The sedimentary rocks of the Coastal Plain include in general upper Cretaceous and Tertiary formations. In the part of the Coastal Plain considered here the Tertiary sedimentary formations are either not present or are relatively thin. The Edwards Plateau shows generally the formations of the Comanchean Series. A table showing the Cretaceous and Comanchean formations found in the Uvalde district and in the region of Austin is given below.

UVALDE	Thickness Ft.	AUSTIN	Thickness Ft.
Pulliam	100–200	Navarro	400
Anacacho formation	300–400	Taylor marl	540
Austin chalk	355–400	Austin chalk	410
Eagle Ford shale	75	Eagle Ford shale	30
Buda limestone	60– 75	Buda limestone	45
Del Rio clay	50– 60	Del Rio Clay	80
Georgetown formation	30	Georgetown formation	80
Edwards limestone	520	Edwards limestone	300
		Comanche Peak limestone	40
Comanche Peak limestone	60	Walnut clay	15
Glen Rose formation	60– 70	Glen Rose formation	450
		Travis Peak formation	100

It will be noted that some differences in the sedimentary sections exist in the two localities which represent the two ends of the belt in which the igneous rocks occur. In the discussion of the geology of the igneous rocks frequent mention will be made of the sedimentary formations and for that reason the reference table is introduced.

The sedimentary formations of this region consisting of limestones, chalks, sandstones, shales and clays in general dip gently southeastward. Faulting connected with the Balcones system and folding have rearranged their structure. A certain part of the structural features now seen in the sedimentary rocks has been caused by the forces of igneous intrusions and such features are discussed in the present section of the report, though no attempt is made to discuss general stratigraphic or structural conditions.

In the discussion of the geology of the igneous rocks which follows, an attempt is made to explain and describe the nature of the igneous activity, its relation to structure, the types of igneous masses found and their age. Necessarily a certain part of such a discussion must be speculative, although in so far as possible speculation is avoided.

It is not practicable to show on a single map the geologic details of all of the occurrences of igneous rocks known in the region. However, in Plate I, the location of each known body of igneous rock and of serpentine rock is shown. In the case of most of the occurrences, size is necessarily exaggerated since otherwise the scale employed on the map would not show them. Because of the exaggeration, the locations shown are approximate rather than exact. To supplement the map, a list of occurrences is given showing the location of all of the igneous masses reported in the past or found during the course of the present work. This list very probably is not complete and additions to it are to be expected when detailed mapping in the counties along the Balcones Zone has been completed. The list in the present section of the report includes only the massive igneous rocks; occurrences of serpentine (altered igneous rock) are shown in another list later in the report.

Plate I, the map showing the igneous bodies, shows only the locations of the igneous rocks. It is supplemented by figures and sketches of various types of occurrences which are thought to be characteristic. In the list which follows each igneous mass wherever possible is classified as to its mode of occurrence. In many cases the igneous rocks occur in a region of extensive alluvial materials that obscure the relations between the igneous masses and the sedimentary rocks.

LIST OF OCCURRENCES

Bandera County.—1. Two miles west of Bandera on the Batto farm is found a dike of limburgite in the Glen Rose limestone. The dike is about 10 feet wide and stands vertically between walls of limestone with an E–W strike. At this locality the dike can be traced for about 100 yards, but Tait,[2] who discovered it, reported that he followed it for one-fourth of a mile. An extension of the dike about 4 miles to the west has recently been found by G. Kirby and J. M. Dawson.

2. Seven miles south of locality No. 1 two dikes of altered basaltic material have recently been found by G. Kirby and J. M. Dawson. The occurrence of all of the Bandera County dikes has been made the subject of a recent paper by Kirby and Dawson along with M. A. Hanna.[3]

Bexar County.—1. A plug of basalt 10 miles northeast of San Antonio is reported by Deussen.[4] However, it is not shown on the map accompanying his report and was not seen during the present work.

Comal County.—1. In western Comal County a dike of nephelite-basalt is found 300 yards above the mouth of Honey Creek and one-half mile from the Kendall County line. The dike is 5-15 feet wide, varying in width along its strike, and is traceable for about 200 yards. It stands practically vertically in Glen Rose limestone and has a strike NE-SW. Apparently, the present exposed surface of the dike is near its original upward extent, since the surface now exposed disappears and reappears beneath limestone. Alteration to serpentine is extensive in this dike, fresh material being limited to the central portion and even here olivine is partially altered.

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[2]Tait, J. L., Report of Geologist for Southern Texas. Texas Geol. Surv. Report, Progress 1 (1888), pp. 64–69, 1889.

[3]Kirby, G., Dawson, J. M. and Hanna, M. A., Igneous Dikes in Bandera County. Econ. Geol. Vol. XXII, pp. 621–624, 1927.

[4]Deussen, A., Geology of the Coastal Plain of Texas West of Brazos River. U. S. Geol. Surv. Prof. Paper, 126, p. 120, 1924.

2. Two and one-half miles east of locality No. 1 another exposure of probably the same dike is seen. The width is about the same but the strike is more easterly.

Hays County.—1. In northern Hays County, one mile southwest of the Travis County line and on the northwest side of the road running southwest from Cedar Valley, Travis County, a small body of basalt is reported. The mass was not seen but reports indicate that it is a small circular plug-like mass intrusive into the Edwards limestone. It is on the upthrown side of the Balcones Fault and about 10 miles back from the main fault zone.

2. Deussen[5] states that several igneous plugs are found in southwestern Hays County. However, he has not given exact localities and the masses do not appear on his map. Search has failed to reveal these occurrences, but it is possible that they will be found in the future.

Kinney County.—1. Palmer Hill 5 miles southeast of Brackettville, is a low hill standing about 50 feet above the surrounding country. The crest of the hill is capped with olivine-basalt which lies upon Austin chalk. The chalk is undisturbed, essentially horizontal and shows no metamorphic effects. The igneous body is apparently the remnant of a sill intruded into the Austin.

2. Las Moras Mountain, 4 miles north, slightly east of Brackettville, is a prominent hill standing 400 feet above the general surface. It is roughly oval in shape, being over a mile long and about a mile wide. The upper 100 feet of the hill consists of nephelite-basalt, below which is about 30 feet of Austin chalk followed by Eagle Ford shale, which forms the base of the hill. The contact of basalt and limestone can be seen in gullies on the west flank of the hill. The chalk occupies a horizontal position beneath the basalt and the latter appears as a sill, the covering of which has been removed. A sketch of the occurrence and additional discussion is given on page 40.

3. Pinto Mountain. 9 miles north of Brackettville, is a hill about 300 feet high. The hill is capped by 80 feet of olivine-basalt lying on top of Eagle Ford shale with a horizontal contact. The basalt is, no doubt, a sill. The underlying shale has been slightly baked by the intruding igneous rock.

4. At Little Pinto Mountain the conditions seen at Pinto Mountain are duplicated, except that the sill is only 15 feet thick. The rock is olivine-basalt.

5. Hill 2 miles north of Las Moras Mountain. This occurrence is much the same as that at Las Moras Mountain. A low hill is capped by about 70 feet of nephelite-basalt, lying in this case on Eagle Ford shale. The relations between the igneous rock and the

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[5]Deussen, A., *op. cit.*, p. 4.

shale are not as plain as in the case of Las Moras Mountain, but all evidence present suggests an uncovered sill.

6. Turkey Mountain, 14 miles northeast of Brackettville and 13 miles northwest of Cline, is a very prominent hill standing about 450 feet above the plain. The upper 200 feet consists of nephelite-basalt lying horizontally above sedimentaries. The stratigraphic level of the basalt is the top of the Eagle Ford which is well exposed below. Conditions here are simply a repetition of those in other occurrences in the county and seem to indicate a sill of basalt uncovered by erosion. This sill is the thickest found during the present work.

7. Elm Mountain, 7 miles east, slightly north, of Brackettville, is still another occurrence of the sill type. The hill is about 200 feet high, and the upper 35 feet consists of nephelite-basalt. Immediately below the basalt is Austin chalk, the contact between being horizontal. The surface area of the basalt here is small, only the tip of the hill being covered. The occurrence represents a sill uncovered and nearly destroyed by erosion.

8. A small hill 5 miles northeast of Las Moras Mountain has been reported to contain basalt. The occurrence was not seen, but judging from reports, is a plug eroded to the level of the Del Rio formation which surrounds it.

9. Specimens of gabbro were seen reported to have come from a locality in the north part of the county near old Tularosa Post-office. The locality was not seen but is shown on the map.

Medina County.—1. On Mumme's ranch, 13.8 miles north of Hondo and one-half mile south of the ranch house, a small plug of olivine-basalt occurs. The plug is about one-eighth of a mile in diameter and is surrounded by Edwards limestone. The igneous rock occupies a depression, and in relation to the surrounding limestone, shows steep contacts. The form is that of a plug. Little or no evidence of metamorphism was seen.

2. On King's Ranch, 2 miles south of the ranch house and 1½ miles upstream from the mouth of Cow Creek, a dike of olivine-basalt is found. The width of the dike is 15 feet and the strike is N 55° E. It is traceable about one-fourth mile and in places is well exposed, showing not only the wall-like expanse of dike material, but also the enclosing Glen Rose limestone. The limestone on both sides of the dike is jointed and shattered parallel to the trend. Near the contact alteration has produced a zone of soft serpentine-bearing rock. At a point near the west end of the dike and at the south contact a shaft was sunk many years ago in the hope of finding mineral deposits of value. The dump does not show metallic minerals and at no point along the dike is evidence of them seen.

3. King's Ranch, 2 miles south of ranch house, is the locality of another body of igneous rock. The rock occurs as an irregular-shaped mass one-eighth mile in diameter surrounded by Glen Rose limestone and is composed of olivine-basalt. Contacts are not exposed, but judging from the shape and relations to surrounding rocks the occurrence is intrusive and probably a plug.

4. An igneous body has been reported by ranchmen to be located 11 miles southwest of D'Hanis. It has not been seen but float specimens from the locality are nephelite-basalt.

Travis County.—1. A dike of limburgite is found 13 miles west of Austin on the Barton Springs-Bee Cave road 3 miles southeast of Cameron's Ferry, exposed in the bed of Barton Creek. The dike is 15 feet wide and stands vertically between walls of Glen Rose limestone with a strike of N 20° E. In addition to the main exposure, the dike can also be seen 300 yards S 20° W, and also near the road on the west side of Barton Creek, 500 yards N 20° E of the first exposure. Dr. T. L. Bailey, formerly of the Bureau of Economic Geology, found this occurrence and described the rock, his notes being on file in the records of the Bureau.

2. Pilot Knob, 7 miles southeast of Austin, 1 mile south of Onion Creek, and 3½ miles east of Bluff Springs, is probably the best known igneous rock locality of the entire Balcones zone. It was described as early as 1890 by R. T. Hill[6] and has been the subject of much discussion since that time. Pilot Knob is a roughly circular hill of limburgite, slightly more than a mile in greatest diameter, rising 200 feet above the surrounding prairie. Details of the geology are discussed on page 35.

3. In south Austin on the property of George Parkinson is found an irregularly shaped mass of nephelite basalt in Austin chalk. Near by are extensive deposits of the serpentine rock.

Uvalde County.—1. Inge Mountain, 4 miles south, slightly east of Uvalde, is a conical hill about one-fourth mile in diameter, standing about 100 feet above the surrounding country. Figure 2 shows a view of the locality. The hill is entirely surrounded by alluvium of the Leona River flood plain so that the relations of the mass cannot be seen. It is composed of the Uvalde phonolite which is blue-gray in color containing abundant phenocrysts of hornblende, nephelite and feldspar. Occasionally nests and stringers of pegmatitic material are found occurring in the normal phonolite and grading into it. Although the relations of this mass of rock to the sedimentary rocks cannot be seen, the shape and dimensions suggests a plug from which a great deal of sedimentary material has been removed by erosion.

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[6]Hill, R. T., Pilot Knob, A Marine Cretaceous Volcano. Amer. Geol., Vol. 6, pp. 286–292, 1890.

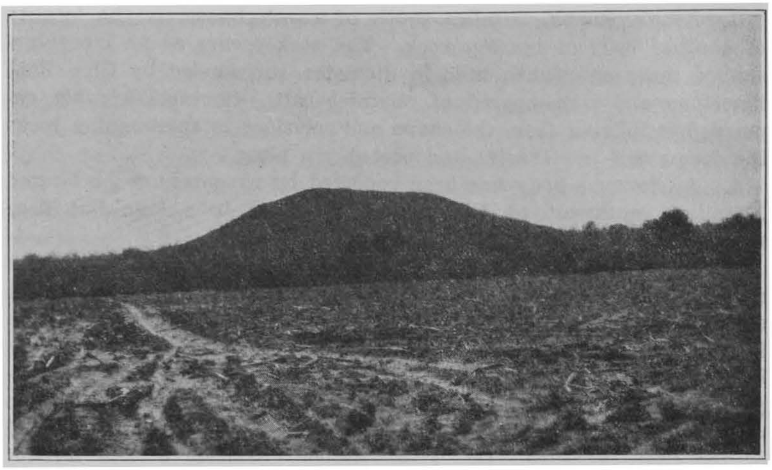

Fig. 2. View of Mount Inge, southwest of Uvalde, composed of Uvalde phonolite.

2. At Ange Siding on the Southern Pacific Railroad, 4 miles northeast of Uvalde, there is a small plug of phonolite, roughly oval-shaped about one-fourth mile in longest dimension. The plug occupies a knoll which rises about 40 feet above the surrounding country. On all sides, except the west, the contact rock is Eagle Ford, while on the west both Eagle Ford and phonolite are flanked by alluvial material. The relations of the igneous rock to the Eagle Ford are best seen along the railroad where a cut has been made through the hill. The sedimentary rock is essentially horizontal and is cut sharply by the phonolite, showing that the igneous body is of a cross-cutting nature. No evidence of metamorphism was seen. The phonolite is dark-greenish in color, very fine-grained, containing phenocrysts of feldspar and nephelite. It breaks with a conchoidal fracture and weathers light gray. Its color is in distinct contrast to that of the Uvalde phonolite of Mount Inge.

3. Near Knippa on the west bank of Frio River is a prominent hill of nephelite-basalt. Quarrying operations of the Texas Trap Rock Company have exposed a face 700 feet long and 115 feet high along the east side of the hill, exposing an excellent section. Details of the locality are given on page 31.

4. Green Mountain, 14 miles north of Uvalde, is a stock or plug of olivine-basalt and gabbro. The locality is a low elongate hill three-fourth mile long located on the upthrown side of the Balcones Fault, about three miles from the main fault. Good exposures of the surrounding rocks (Edwards limestone) are seen and the relations of the igneous rocks to the sedimentaries quite plain. The

sedimentary rocks are undisturbed and are cut sharply by the igneous mass. A slight recrystallization of the limestone is the only metamorphic effect seen. The igneous rock consists mainly of olivine-basalt, but in the south-central part of the stock specimens of gabbro are found. The exact relations of the gabbro to basalt are not exposed but specimens showing gradation from basalt to gabbro are found and it appears that the basalt corresponds to a chilled phase of the gabbro.

5. An unnamed hill 12½ miles north of Uvalde Station and one mile north of Green Mountain is a very small plug of nephelite-basalt in the Edwards limestone.

6. An unnamed hill 15¼ miles northwest of Uvalde Station is a very small plug of nephelite-basalt in the Edwards limestone.

7. At Yucca Siding there are three small bodies of nephelite-basalt within a radius of one mile. All are completely surrounded by wash so that their relations cannot be seen. The shape in each is nearly circular and a plug is suggested. These bodies are in the belt of outcrop of the Anacacho limestone and probably intrude it.

8. Three-fourths of a mile east of the Southern Pacific crossing of Blanco River is a small dike-like mass of nephelite-melilite-basalt. This is surrounded by wash, but is probably intrusive into the Anacacho limestone which outcrops nearby.

9. On Blanco River, one-fourth mile upstream and one-fourth mile downstream from the Southern Pacific Railway crossing are two small irregular-shaped bodies of nephelite-basalt. They are completely surrounded by wash so that their nature cannot be determined.

10. Blue Mountain, 2 miles northwest of Knippa, is a large stock of nephelite-basalt. The hill is about 300 feet high and consists of two rounded knobs with a saddle between. The dimensions of the mass as exposed are approximately one by one-half miles. All except the west flank of the mountain is covered by wash but on the west Eagle Ford shale is found at the contact. The shale dips away from the igneous mass but shows cross-cutting relations to the igneous rock. No noticeable metamorphic effects are seen. In the saddle between the two prominent knobs of the mountain are found two small areas of Austin chalk, recrystallized and baked. These represent either the roof of the magma or were carried up during intrusion. In either case, a cross-cutting intrusive relationship is demonstrated for the two knobs of basalt are nearly 100 feet above these areas of chalk.

11. One mile north of Knippa there is a conical hill of nephelite-basalt. It rises abruptly for 150 feet above the surrounding country which is an alluvial flat. No sedimentary rocks are exposed, but the shape of the igneous mass suggests a plug. It is about one-fourth mile in diameter and nearly circular in outline.

12. On Frio River, 1¾ miles north, slightly west of Knippa, there is found a dike-like body of nephelite-basalt standing above the wash and alluvial material that completely surround it. The exposure is slightly less than one-fourth mile long and about 150 yards wide. On the banks of the river good exposures of the rock are found. Here there is considerable alteration to serpentine and gradation can be traced from solid basalt through partly altered rock to serpentine. Cracks and joints in the rock are filled in some cases with fibrous serpentine deposited after the other alteration had occurred. Individual fibers are up to one-fourth inch long but no single vein can be followed more than a few feet.

13. Two miles north of Ange Siding there is a circular plug of phonolite in the Edwards limestone, forming a low hill and being less than one-fourth mile in diameter. Apparently a fault passes along the southern flank of the plug since here Buda limestone is in contact with Edwards, as shown by Vaughan.[7] The plug is entirely enclosed in the Edwards which is apparently little disturbed and which has not been metamorphosed.

14. One mile north of Ange Siding there is an irregular-shaped mass of olivine-basalt surrounded by Eagle Ford shale forming a low hill. This occurrence may be either a plug or sill, since the relationship to the sedimentary rocks is not plain. The shales are found on the slope at the bottom of the hill lying horizontally and showing no evidence of metamorphism. The upper surface of the igneous mass shows an extensive development of columnar jointing in which only the cross sections of the columns are seen.

15. One-fourth mile west of locality No. 14 Vaughan[8] mapped a very small body of phonolite, but this was not seen during the course of the present work.

16. At the old Dr. Wish Ranch on Dinner Creek, four miles southeast of Knippa, there are four bodies of nephelite-melilite-basalt forming low knolls above the wash that completely surrounds them. The largest body is one-fourth mile in diameter and the smallest is only a few yards across. All four are grouped within a small area and it is probable that they are parts of the same mass over which alluvium has been deposited in places.

17. One and one-half miles southeast of locality 16 on the old Uvalde-Sabinal road is a body of nephelite-melilite-basalt about 200 yards in diameter, surrounded by wash.

18. In the alluvial flat northeast of Connor's Ranch and southeast of Long Hollow three bodies of igneous rock are found. None of these stand very conspicuously above the plain and all are completely surrounded by alluvial material so that their relationships cannot be

[7]Vaughan, T. W., U. S. Geol. Surv., Geologic Atlas, Uvalde Folio No. 64, Historical Geology Sheet, 1890.

[8]Vaughan, T. W., *op. cit.*

determined. The largest mass is of nephelite-melilite-basalt and is of considerable size. The others are of nephelite-melilitite-basalt and nephelite-basalt.

19. Near Connor's Ranch on Frio River there are four small bodies of phonolite exposed along the stream. The largest is immediately southeast of the ranch house and forms a round knoll about 200 yards in diameter. The other three masses are found southeast from this point, the most distant being about 1 mile. The four bodies of phonolite lie in nearly a straight line, the bearing of which is N 45° W. Their comparatively small surface exposure and relation to each other suggests that they constitute a dike of which only occasional parts are exposed. The surrounding terrain is a wash filled valley so that it is impossible to determine exactly the relation of the igneous rocks to each other and the sedimentary rocks.

20. Three-eighths of a mile west of Connors' Ranch is a low circular hill of nephelite-basalt slightly less than one-fourth mile in diameter. This occurrence is completely surrounded by wash and there is no indication of the origin other than the circular outline of the igneous mass.

21. Black Waterhole, 6 miles east, slightly north of Uvalde, on Frio River at the Huston Ranch, is the locality of one of the most interesting occurrences of igneous rock in the entire Balcones region. Details of the occurrence are given on page 26.

22. One-half mile upstream from locality 21 a very small outcrop of nephelite-melilite-basalt occurs in the stream bed. The areal extent is only a few yards and the shape suggests that the very top of a plug has here been uncovered by erosion. The basalt is surrounded by Austin chalk, slightly metamorphosed and dipping away from the igneous rock. The chalk is much jointed and shattered near the igneous mass due probably to the force of the intrusion. The basalt itself is considerably altered to serpentine and has weathered in concentric structure.

23. Two miles south, slightly east of Black Waterhole, two masses of phonolitic rock and one of limburgite are closely grouped. The phonolitic rocks are, strictly speaking, nephelinite and a related rock and form prominent hills about 100 feet high, and slightly less than one-fourth mile in diameter. The distance between the two hills is about one-half mile, and located in it with very little topographic relief is the mass of limburgite outcropping over a few square yards. The relations of these three masses of rock cannot be seen for they are flanked by wash. The phonolitic masses appear exactly as does Mount Inge.

24. One mile east of Black Mountain a small mass of nephelite-melilite-basalt was mapped by Vaughan.[9] It intruded the Buda limestone and appears with a circular outline and practically no relief.

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[9]Vaughan, T. W., *op. cit.*, Historical Geology Sheet.

25. A stock of phonolite is found 3 miles north of Uvalde Station practically in the main fault zone. It is elongate oval in shape, being one-fourth by one-eighth mile in dimensitons. The surrounding rock is Buda limestone which is cut at high angles by the phonolite. The phonolite is dark greenish-gray in color weathering light gray. It contains abundant phenocrysts of feldspar, hornblende and nephelite. Considerable variation exists in the rock and some areas suggest flow structure. The mass is extensively sheeted, the joints being vertical and striking N 60° W.

26. The Taylor Hills, 5 miles southeast of Uvalde, is a large mass of nephelite-melilite-basalt, occurring as a hill 2 miles long and 1 mile wide. Its relations cannot be established except that it is older than the Uvalde formation which may be Neocene. On the north the gravels of this formation lap upon the basalt, while elsewhere the mass is flanked by the alluvial material of the Leona formation. An extension of the igneous mass occurs to the northwest where a small body of similar rock is found but separated from the larger mass by an interval of one-fourth mile covered by alluvium.

27. One mile north of the central part of the Taylor Hills a very small knob of nephelite-basalt is found. This is entirely surrounded by materials of the Uvalde formation which are apparently younger in age than the basalt.

28. Rocky Hill, 2½ miles southwest of Uvalde, is the location of a small intrusive body of phonolite of unusual character. Rocky Hill is three-fourths mile long, oval in shape, and the phonolite forms the southeast end of the hill, being considerably below the summit. The greater part of the hill is of Edwards limestone, which must owe its present location to faulting, since the normal position of this formation is considerably to the north. The faults, however, are not to be seen. The phonolite mass which covers only a few hundred square feet abuts sharply against the limestone with apparently a sharp contact. The rock itself is light greenish-gray with a speckled appearance due to the presence of groups of green pyroxene crystals separated by alkali feldspar in a finer groundmass.

29. Two miles southwest of Rocky Hill are two very small areas of nephelite-melilite-basalt occurring without relief and surrounded completely by alluvial material.

30. Black Mountain, 3 miles north, slightly east of Ange Siding, is capped by a sill of nephelite basalt. The hill as a whole is about 180 feet above the plain and the upper 80 feet are of basalt. The horizon of the basalt is near the bottom of the Austin for about 40 feet of this material is found beneath the basalt, followed in turn by the Eagle Ford shale. The effect of the sill has been to preserve from erosion a narrow ring of the chalk completely encircling the summit of the hill. The chalk as far as could be told

from rather poor exposures lies horizontally beneath the basalt. It is, however, slightly metamorphosed.

31. On the Concan road, 7½ miles northeast of Uvalde Station, is a small body of olivine-basalt. This is a new locality found during the course of the present work and occurs without relief from the surrounding alluvial plain. The mass is found only by the occurrence of many boulders of the rock scattered over an area about 200 yards in diameter.

32. One-half mile west of Allen Hill and 2 miles southeast of Asphalt Mountain, are three small hills about 350 yards in diameter and 60 feet high composed of nephelite-basalt. These are surrounded by Anacacho limestone and have intruded it with nearly vertical contacts. They are believed to be small plugs.

33. Just southeast of Round Mountain and 4 miles northwest of Uvalde Station, two small bodies of olivine-basalt are found completely surrounded by wash. The nearest consolidated sedimentary rock is Eagle Ford shale, one-fourth mile to the northwest, but the relation of the igneous rock to this exposure cannot be determined.

34. At the Tom Nunn Ranch on Nueces River, 6 miles southwest of Uvalde, is a stock of nephelite-melilite-basalt intrusive into the Austin chalk. The basalt occurs as a low hill about one-half mile in diameter, bordered on the west by chalk and the east by the Uvalde formation. The latter is plainly younger than the igneous rock, since its materials lap upon the stock with an erosional contact. The chalk, on the other hand, is cut sharply by the basalt which stands above it. The shape of the igneous mass and the nature of the contact suggest that the occurrence is a stock.

35. One and one-half miles south of No. 34 are two small bodies of nephelite-basalt. One of these is surrounded by wash so that its nature cannot be seen, but the other intrudes the Pulliam formation which is the youngest Cretaceous formation of this region. The mass is elongate, oval in shape, and appears as a low hill. The contacts are intrusive and the occurrence is apparently a plug.

36. Near Wagontop Hill (Wagon Wheel Hill of older maps), in the southwestern part of Uvalde County, are three small masses of limburgite. These occurrences have furnished specimens the most basic of all of the rocks of the region. They are of additional interest because they are apparently intrusive into the Pulliam formation. The three small bodies, each about 200 yards in diameter, occur nearly in an east-west line. They might be mistaken for the remnants of a sill were it not for the fact that they do not occupy the highest points and that intervening high areas do not contain the basalt. Actual contacts are not determinable, but the shapes of the bodies and their relations suggest that they are plugs. At any rate, they are intrusive into the Pulliam formation and are therefore probably Tertiary in age.

37. Lewis Hill, 10 miles west, slightly north of Uvalde, is capped by a sill of nephelite-basalt. The hill is about 100 feet high and the upper 50 feet is basalt lying horizontally on Austin chalk.

38. Obi Hill, 11 miles west of Uvalde, is the locality of a sill of nephelite-basalt, the horizon of which is Anacacho. The shape of the hill and the capping sill is horseshoe or crescent. The Anacacho lies undisturbed beneath the basalt.

39. At Weymiller Butte, 10 miles southwest of Uvalde, are three bodies of nephelite-basalt, all apparently sills. One is found near the top of the Austin, while the others are in the base of the Anacacho, stratigraphically.

40. Asphalt Mountain, 3 miles southeast of Cline Station, is a conical hill about 200 feet high and one-fourth mile in diameter. The upper 150 feet of the hill is composed of nephelite-basalt, occurring as a sill in the Anacacho limestone.

41. Four miles southwest of the Uvalde Rock Asphalt Company there are three small bodies of olivine-basalt. These appear without relief in the Anacacho limestone in the center of an anticline and can only be regarded as pipe-like intrusions.

42. Near Mustang Waterhole on Nueces River, north of Cline, is one of the largest of the basalt plugs. This occurrence contains both olivine-basalt and gabbro, with relations as at Green Mountain in that the two types appear to grade into each other. The plug forms a hill 2 miles long by 1 mile wide and is flanked on the north and east by Buda limestone and on the south and west by Eagle Ford shale. Intrusive contacts are well shown on the northwest flank where the limestone dips away from the igneous mass, but is cut by it. Immediately at the contact there is an apparent reversal of dip as if the igneous mass after intrusion had settled, carrying down also the adjacent limestone. The limestone is slightly baked and recrystallized near the contact but this effect is not observable more than 300 yards distant. The contact with the Eagle Ford shale is not good since this formation is soft and readily erodes.

43. Downstream from Mustang Waterhole and directly east of No. 42 is a dike of olivine-basalt. It is found in the bed of the stream and its relations to the surrounding rocks were not determined.

44. A small body of basalt has been reported near Cline Station, but was not seen during the course of the present work.

45. In the north side of Cline Mountain, south of Cline Station, there is a sill of basalt at the contact of the Austin and Anacacho. The thickness is about 60 feet but exposures are poor. The sill can be traced for nearly one-fourth mile.

46. In the Edwards plateau region of the county, several miles back from the fault, Vaughan mapped several very small bodies of basalt. These were not seen during the present work. Localities shown by Vaughan are 13 miles northeast of Uvalde Station and at

the old Crane Ranch, 10 miles north of Yucca. At the latter locality three small masses were mapped all reported as nephelite-basalt.

47. Three miles southeast of the Uvalde Rock Asphalt Company and nearly due south of Sulphur Mountain there is a small hill of nephelite-basalt. This is surrounded by Anacacho limestone and appears to be a stock or plug, though its relations are not positive.

48. Southwest of No. 47 at the Smythe Ranch, there is a dike-like mass of olivine-basalt. This is found in the banks of the creek southeast of the ranch house and stands between walls of alluvial material. The mass is 50 yards wide at the widest point and narrows to less than 30 feet. It is traceable about 200 yards. Alteration to serpentine is extensive in this occurrence, all stages of the process being seen. An initial stage here has produced pseudomorphs of serpentine after olivine of a striking blue-green color standing in contrast to the dark gray or black or the rest of the rock.

49. On the west bank of Almos Creek, one-half mile north of the Uvalde-Zavala County line, a circular mass of basalt has been reported by ranchers. It was not seen during the work.

50. West of Nueces River and south of the Southern Pacific Railway is an extensive area of igneous rocks consisting of several separate occurrences but best treated as a unit. The area is described on page 106.

51. Pilot Knob, 7 miles southeast of Sabinal, is a rounded hill of nephelite-basalt one-fourth mile in diameter. It appears to be a plug but its exact relations were not determined.

Zavalla County.—1. In wells drilled for oil and water on the Pulliam and Anderson ranches near the Uvalde-Zavalla County line, nephelite-melilite-basalt was encountered. The wells were irregularly spaced over an area of about two square miles. In most cases the basalt limited drilling operation so that the entire thickness of the rock is not known. In one well several hundred feet of the material was penetrated before the drilling ceased. Evidently a mass of the basalt of about 1 square mile in area is beneath the surface at this point. The average depth to the basalt is 1100 feet.

GENERAL RELATIONS OF THE IGNEOUS ROCKS

From the map showing distribution of the igneous rocks, it can be seen that the rocks occur in isolated masses in a belt a few miles wide, through a distance of more than 200 miles. Large areas lack igneous rocks, as for example, Bexar County, where none are known. On the other hand, certain parts of the district contain great numbers of igneous rock bodies, as for example Uvalde County and to a lesser extent Kinney and Travis counties. In the remainder of the belt only occasional occurrences are known, there being four in Medina County, four in Bandera and one or more in Hays County. One of the occurrences listed is not exposed at the surface but was discovered in drilling for oil. The striking feature of the geographic distribution of the rocks is the linear shape of the area in which they occur and its relation to other geologic features. Apparently reliable information shows that the belt of igneous rocks continues into northern Mexico in the region near Del Rio and it has been frequently stated that igneous rocks of southwestern Arkansas occur in a northeastward extension of the same belt.

The close correspondence of igneous activity and faulting of the Balcones system shows that a genetic relation exists between them. In general it is suggested by the distribution of the rocks both geographically and geologically that they are eruptions of the fissure type. They occur in a linear belt in which pronounced faulting is common and they are restricted laterally to the belt in which the faulting was most effective.

The magmas were predominantly basaltic with minor phonolitic phases. Such magmas are regarded as having originated at great depths. Related faults would also extend great distances vertically. If the igneous activity is related directly to the faulting it is probably true that faulting occurred in the region as early as Eagle Ford time, since some of the igneous rocks appear to be of that age. Furthermore, an active fault zone prevailing from Eagle Ford time into the Tertiary is a logical conclusion on the same basis since many of the igneous masses are of the latter age.

Nature of the Igneous Activity.—It is believed that the igneous activity is related to the faulting of the Balcones system, and that the various igneous bodies have been localized by the fissures developed through faulting. The greater number of igneous occurrences known are of an intrusive nature and include plugs, stocks, dikes, sills and possibly laccoliths. It is possible that a small number of the igneous bodies were extrusive and constituted volcanoes, for there are some masses whose nature cannot be determined. The evidence for this is not impressive and it is doubted whether such activity occurred. The serpentine, to be discussed later, is thought to include occurrences of the extrusive type but no occurrence of unaltered massive igneous rock can be positively classed as a surface flow.

In the following pages the best examples of various types of occurrences are described. These include stocks, plugs, sills, and dikes. As far as known no laccoliths occur, though this classification has been ascribed to certain of the masses by other writers as will be noted presently. Since the map accompanying the report is on a scale which prohibits the delineation of detail, sketches and rather full descriptions are given. The descriptions given will perhaps serve as guides to which other occurrences may be referred.

STOCKS AND PLUGS

Under the general heading of stocks and plugs are included here all of the igneous bodies in the district that exhibit cross-cutting relations and steep contacts with the surrounding sedimentary rocks. The type is the most common throughout the igneous district, the differences between individual examples being mainly of size. A number of the stocks or plugs are so exposed that their relations to the surrounding rocks are well shown, but the greater number are surrounded by mantles of débris and wash so that their exact nature cannot be determined. No attempt is made to describe all of the stocks and plugs known. A few of those best exposed are discussed as examples of the class. The list of occurrences already given shows those known in the district and brief notes on many of them are given.

Green Mountain.—One of the largest of the igneous plugs is found at Green Mountain in Uvalde County and additional notes on the occurrence are given in the list of occurrences. The plug forms a low rounded hill one mile long and one-half mile wide on the Edwards Plateau 14 miles north of Uvalde and 3 miles back from the main Balcones Fault. Erosion has sharply separated the hill from the surrounding Edwards limestone so that it appears to occupy a depression, the rim of which is composed of sedimentary rocks. The limestones of the surrounding rim are well exposed and the contact of basalt with limestone can be seen at a number of places. The limestone beds on all sides of the igneous mass are nearly horizontal and have not been disturbed by the intrusion. The contacts seen are steep and the whole mass is roughly pipe-shaped and must cut the sedimentary beds nearly vertically.

Contact metamorphism is limited to a slight hardening and recrystallization of the limestone, this effect extending outward about 300 yards. Since the contacts of igneous rock and limestone are nearly vertical this distance can be taken as the maximum for the effect of the intrusion on the surrounding rock.

The igneous rock includes both basalt and gabbro, the latter occupying a position in the central part of the mass and being subordinate in amount. Specimens showing gradation between the two types are found and it seems evident that both were derived from the same magma. One specimen of gabbro, however, contained a small inclusion of basalt suggesting that some movement of the gabbro magma occurred subsequent to crystallization of basalt. The production of the two varieties of rock in this mass has probably resulted from the difference in the physical conditions of the central and outer parts of the magma.

Black Waterhole.—One of the most interesting igneous plugs of the region is found at Black Waterhole on Frio River, 7 miles east of Uvalde on the Huston Ranch, just upstream from the road crossing. The plug appears as a circular low dome one side of which has been cut away by the river leaving a cliff several hundred yards long and 70 feet high in which the rocks are well exposed. On the other flanks of the plug alluvial materials mask the contacts, though occasional small exposures of sedimentary rocks show that conditions are similar on all sides of the mass. The downstream end of the exposure also is partly obscured by wash, but sufficient exposures are preserved to show that it resembles the better exposed area upstream, though fewer details can be observed.

The cliff exposed along the stream consists of nephelite-melilite-basalt with columnar jointing flanked on the northeast by sedimentary beds composed of conglomerate and finer clastics and a few lenses of limestone and sandstone. These beds are thought to be a basal conglomerate and are unusual in that the materials are largely fragments and cobbles of basalt altered to serpentine. The material resembles superficially a tuff or volcanic breccia and is thought to be sedimentary because the conglomerate beds contain rounded pebbles and cobbles of limestone and shale and a few fossils.

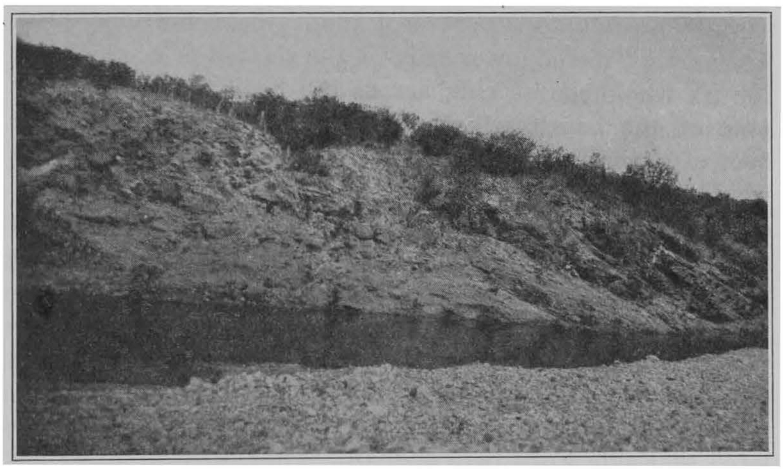

Fig. 3. View of Black Waterhole, Uvalde County. The dipping beds at the right are serpentine.

Nearly one-half of the exposure is composed of basalt, the remainder being the sedimentary beds which disappear upstream. The contact between the igneous and sedimentary rocks is nearly in the center of the cliff and is fairly well exposed, though a small ravine cuts it and obscures part of its extent. In the lower 50 feet the contact is practically vertical, the basalt cutting sharply across the sedimentary beds. In the upper part of the section the basalt mass widens so that its profile suggests a mushroom shape. The expanded part of the igneous mass extends laterally about 70 feet and has a maximum thickness of approximately 20 feet. Its original thickness may have been greater because the upper surface has been eroded to its present position. The section is shown in Figure 5 while Figures 3 and 4 show views from the locality.

Only one flank of the igneous mass is exposed but since the plug is circular in outline it is possible that the outline was originally similar for its entire circumference. At the downstream end of the exposure this is suggested but the exposure is too poor to warrant a definite conclusion. Vaughan[10] regarded this occurrence as a laccolith but such a classification does not seem to fit the conditions seen. The contact in the lower part of the section is vertical and for its whole course cuts across the bedding. The upper part of the basalt which spreads outward might be the floor of a laccolith eroded to its roots. In this, the laccolith would have occupied a space in sediments now entirely eroded away. The present exposure would be the feeding channel of such a laccolith and would be a plug. As shown in the sketch, the sedimentary beds dip from the intrusion. This may indicate a laccolith buried beneath them but certainly not exposed. The conditions seen are much more characteristic of a plug than of a laccolith.

The sedimentary rocks at Black Waterhole were correlated as Eagle Ford by Vaughan. They, of course, do not correspond to the normal Eagle Ford shale but stratigraphically appear equivalent to this formation. They are overlain by Austin chalk to the northwestward and occupy the normal position for the Eagle Ford. The occurrence of these conglomerates composed of fragments of altered basalt records basaltic igneous activity in the region as early as

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[10]Vaughan, T. W., U. S. Geol. Surv. Geological Atlas of the United States, Uvalde Folio No. 64, p. 5, 1900.

Eagle Ford time. The location of the original igneous rocks furnishing the materials in the conglomerate is unknown, but judging from the coarse conglomerate must have been nearby.

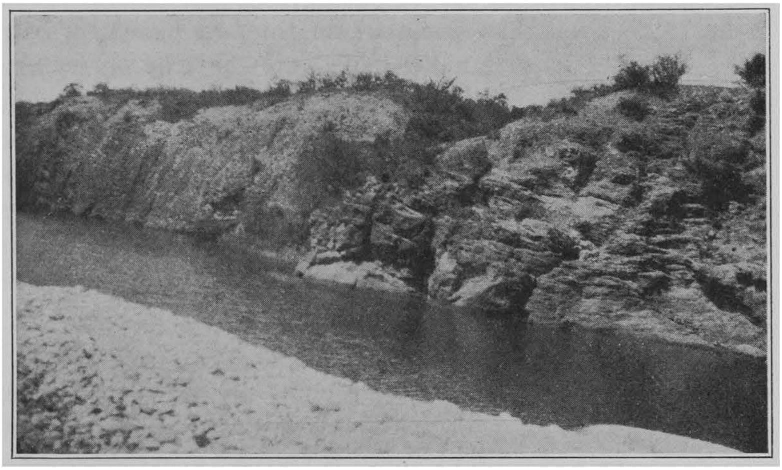

Fig. 4. View at Black Waterhole, Uvalde County. The stratified material at the right is serpentine. At the left is columnar basalt with the contact near the center of the view.

The plug at Black Waterhole gives considerable information on the relation of the igneous rocks to structure. The sketch figure shows the dips prevailing in the sedimentary rocks at the exposure. Northwestward about one-half mile and beyond the limits of the sketch Austin chalk is exposed in the river bed and dips away from the igneous mass conforming to the dip seen near the exposure downstream. The chalk is highly jointed and the joints are disposed radially and concentrically with reference to the plug at Black Waterhole. Followed northward the dip reverses abruptly as a small igneous mass outcropping in the stream bed is approached. The dip and jointing appear to be coincident with the location of the igneous rocks and apparently were developed by the intrusion.

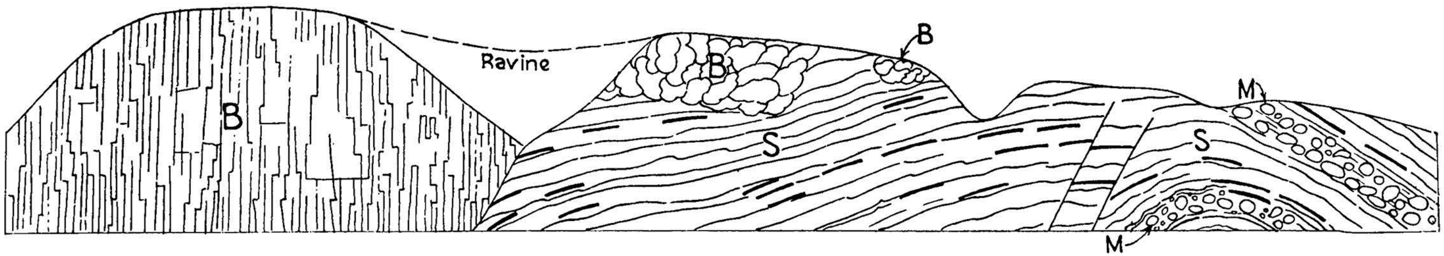

Fig. 5. Sketch showing cross section at Black Waterhole, Uvalde County. *B* is unaltered or slightly altered massive basalt. *S* is sedimentary serpentine, the dips of which are shown by heavy black lines. *M*, conglomerate beds of serpentine.

Immediately adjacent to the plug at Black Waterhole another striking structural feature is shown. This consists in a slight reversal of dip of the sedimentary beds. The sketch shows the dips prevailing and gives some idea of the structure. If the reverse in dip is uniformly developed entirely around the plug, the resulting structural arrangement would have the shape of a funnel. The whole structure around the plug seems to be somewhat similar to the funnel and anticlinal ring structure of the Mexican intrusions described by Garfias and Hawley.[11] As already shown exposures do not exist entirely around the plug but the scanty exposures suggest that the structure is similar to that exposed along the stream.

Knippa.—A third igneous plug is located at Knippa, Uvalde County, and is the site of an extensive quarrying operation carried on by the Texas Trap Rock Company. The rock is used for road-building and concrete aggregate being of excellent quality for these purposes. The quarry face opened was 115 feet high and 700 feet long when seen in March, 1927, affording an excellent cross section of the igneous mass. The plug appears as a conical hill about one-fourth mile in diameter and 130 feet high. Frio River flows along its eastern flank and has been deflected by the resistant igneous rock. The sedimentary rocks intruded are exposed only on the northern side of the mass which elsewhere is flanked by alluvial material. The section of sedimentary rocks present, however, shows plainly the relations at that point and these are probably characteristic for the whole occurrence. Figure 6 is a diagramatic sketch showing the cross section of the quarry face and Figures 7 and 8 show views of the quarry face.

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[11]Garfias, V. R. and Hawley, J. N., Funnel and Anticlinal-ring Structure Associated with Igneous Intrusions in the Mexican Oil Field. A. I. M. E. Bull. 128, pp. 1142–1159, 1917.

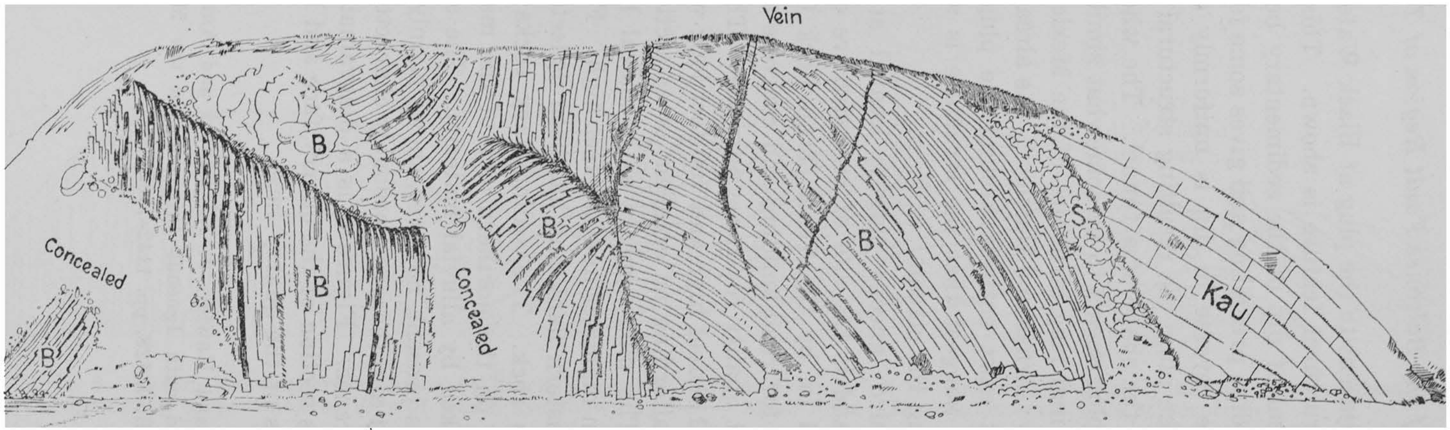

Fig. 6. Sketch showing cross section of quarry face at quarry of Texas Trap Rock Company, Knippa, Uvalde County. *B* is basalt, largely columnar with columns inclined at various angles. *S* is a zone of serpentine-bearing material formed by alteration of the basalt. *Kau* is Austin Chalk which was intruded by the basalt and which dips away from the igneous mass. Vertical scale exaggerated.

The sedimentary rock in contact with the basalt is Austin chalk. The contact dips westward at an angle of 55 degrees, while the dip of the chalk beds is 10 degrees. The basalt thus is seen to cut across the bedding of the sedimentary rocks. The outer margin of the igneous rock next to the contact is weathered to a greenish serpentine-bearing rock very similar to the serpentine of the oil fields. It grades into fresh basalt and is very evidently a weathering product *in situ*. The thickness of the weathered zone is 30 feet. The igneous occurrence was called a laccolith by Vaughan, but as in the case of Black Waterhole, seems to fit better the definition of a plug. There is no evidence of floor upon which the igneous rock rests and this with its circular outline and cross-cutting character suggests that it is a plug. It is true that significant exposures are lacking except as shown in the figure but there is every reason to believe that the same conditions prevail beneath the wash on all sides.

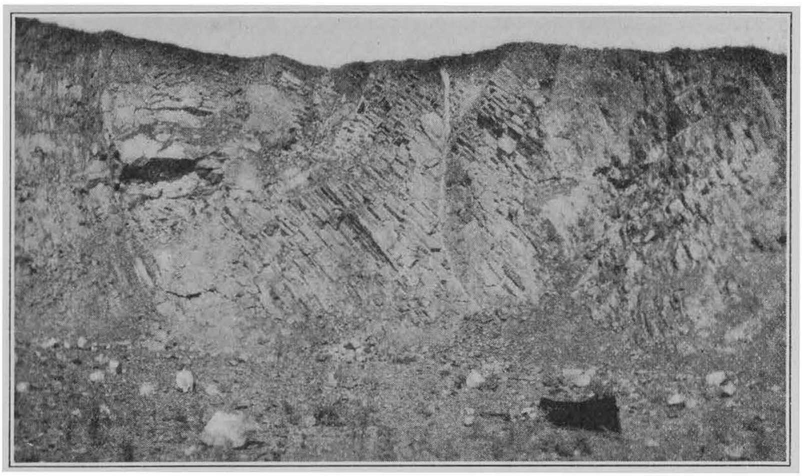

Fig. 7. Quarry face of the Texas Trap Rock Company's quarry at Knippa, Uvalde County. Inclined columnar jointing and a vein are shown.

In the sketch and views illustrating the Knippa quarry it will be noted that columnar jointing is exceedingly well developed. The columns are polygonal, some being hexagonal, others pentagonal, with diameters of as much as 3 feet. The jointing is not uniformly developed throughout but varies greatly, as shown by the sketch. In the central part of the quarry the columns are essentially vertical but elsewhere are inclined at various angles. Some of the junctions of sets of columns suggest faulting but this is improbable. The arrangement of the columns in the manner seen is rather common to basaltic rocks and has been previously described. It is due to unequal cooling of the rocks after consolidation. Iddings[12] has figured a very similar occurrence from a quarry at Orange, New Jersey, and has described in detail the course of cooling and contraction which produces such arrangements of the basalt columns. Extracts from his discussion are given below.

> When a homogeneous solid cools from a plane surface at such a rate that there is an appreciable difference in the temperature of successive parts from the surface inward, and the cooling is uniform throughout the surface, then the stresses due to contraction of the mass will be uniformly distributed through the surfaced layer of the solid. . . . Where the rate of cooling is not the same at all points on the surface of a rock mass, but varies from place to place, as through convection currents in the atmosphere over a lava flow, then the direction of the planes of fracture will not continue normal to the cooling surface. . . . It (isothermal plane) will curve downward and the fractures normal to it will diverge and curve, resulting in curving cracks diverging from the cooling surface. . . . When two systems of prismatic cracks approach each other at an inclination, the direction of advance of each system is changed in such a manner that the prisms curve so as to meet at a more acute angle. . . . The cause is found in a change in the rate of cooling in the rock near the junction of two such systems of prismatic fracture.

The quarry itself furnishes a source of good specimens of secondary minerals. In the upper right of Figure 5 a vein is shown composed of such minerals. In addition the

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[12]Iddings, J. P., Igneous Rocks, Vol. 1, pp. 320–327, 1920.

surfaces of many of the basaltic columns are covered with crusts composed of crystals. The common minerals of both veins and the crusts are calcite and serpentine. The calcite occurs both as excellent groups of crystals and as a fine gouge-like material. The serpentine, derived apparently directly from the basalt in some specimens, is brilliant green in color. The vein figured is one of several encountered during the quarrying operations. The vein material occupies contraction joints which are not continuous and which pinch out with depth. The material of the veins is not suitable for crushed rock and constitutes a source of waste in the quarry.

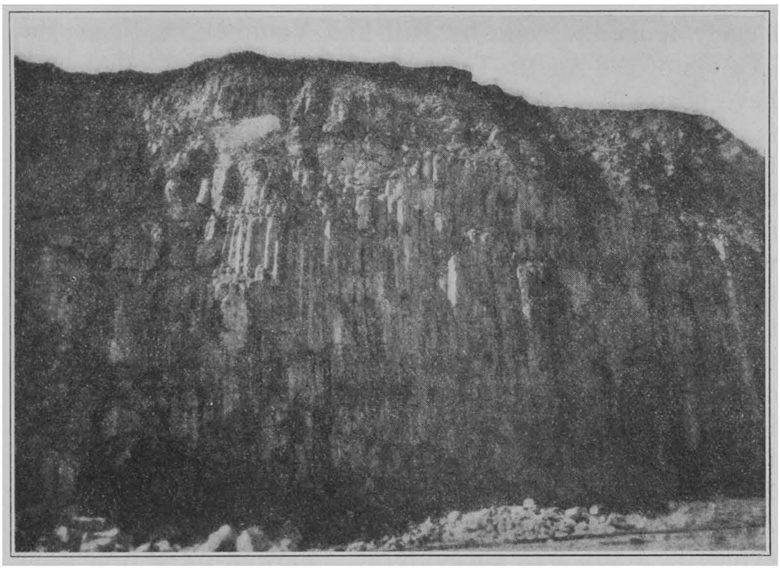

Fig. 8. Quarry face of the Texas Trap Rock Company's quarry at Knippa, Uvalde County. Columnar jointing near the center of the quarry face is shown.

Pilot Knob.—Pilot Knob is located in Travis County, 7 miles south of Austin and 1 mile from Onion Creek, which practically encircles it. The knob is a roughly circular hill of limburgite slightly more than a mile in diameter standing more than 200 feet above the surrounding plain. Three eminences mark the summit of the hill, rising from lower areas of the flanks of the mass. Surrounding Pilot Knob, especially to the west and north, are low ridges of Austin chalk which give to the locality an amphitheater effect. Onion Creek a mile to the north has cut a deep canyon in the Austin chalk which is the contact rock on that side. On the south and east the igneous rock is generally in contact with Taylor marl, though one small outcrop of Austin also occurs on this side. On the southern part of the igneous mass two blocks of chalk, a few yards square, are found resting on the igneous rock, being either roof pendants or xenoliths.

Figure 9 shows the areal geology of the locality taken largely from the folio by Hill and Vaughan.[13] From the location of the Austin-Taylor contact it is evident that both have been affected by the intrusion and are older than the igneous rock. Dips of the Austin are observable between Pilot Knob and Onion Creek and are away from the igneous mass. The Taylor being a soft formation does not permit such observations. Since the igneous mass is in contact with both Austin and Taylor, it is probable that both were intruded by it with cross-cutting relations. The slope of the contact between limburgite and the sedimentary formations is not exposed so that the shape of the mass downward cannot be told. A well drilled on the northwest flank of the igneous mass penetrated altered limburgite to a depth of 556 feet where it passed into limestone. From this depth to about 1970 the samples were of various sorts of sedimentary rock. At about 1970 a thickness of some 10 feet of igneous rock, evidently a sill, was encountered, followed by sedimentary rocks to the bottom of the test at 2445 feet. This well, assuming, the igneous material to be in place, shows that the igneous mass does not continue vertically downward under its present exposure. Were it not for the relations of the igneous rock to the Austin chalk and Taylor marl, the well

[13]Hill, R. T. and Vaughan, T. W.. U. S. Geol. Surv., Geologic Atlas, Austin Folio No. 76, Historical Geology Sheet, 1902.

log would suggest a laccolith. It is probable the shape downward is quite irregular and that at slight depths the diameter is much less than at the surface. The well log further suggests that a mushroom shape may be present.

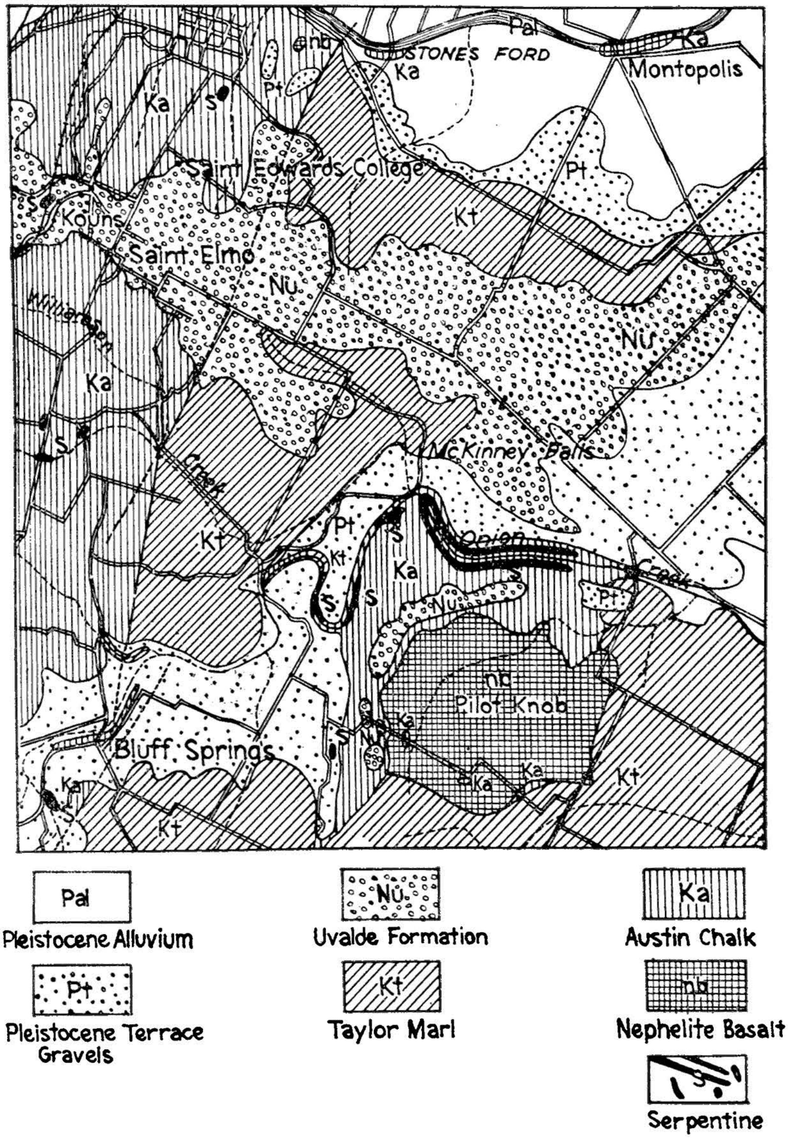

Fig. 9. Geologic map of Pilot Knob and vicinity. (After Hill and Vaughan.)

On the steeper parts of Pilot Knob the rock is comparatively fresh, only a thin oxidized coat being present. On the gentler slopes weathering has resulted in the accumulation of soft greenish to yellowish altered material consisting largely of serpentine and corresponding to that found in the quarry at Knippa. Much of the material has been carried from the higher parts so that there is a considerable accumulation, the thickness of which is not known. Many of the samples from the well mentioned above contain this material and it is possible that the well did not penetrate igneous rock in place, but only the weathered material washed down from the heights. If this is the case, the well log gives no information as to the shape of the igneous mass. Descriptions of samples from the well, in the files of the Bureau of Economic Geology, mention sand, calcite, and other sedimentary materials in most of the samples from the upper 550 feet. It is evident that some of the samples at least were mixtures and probably clastic in nature.

Contact metamorphic effects are prominent at Pilot Knob in the Austin chalk. The chalk near the contact and in the xenoliths is crystallized to a hard coarsely crystallized limestone. In the resulting rock traces of small fossils have been largely obliterated but the larger forms can still be found. There is no evidence of introduction of materials during the course of alteration and net changes chemically are probably negligible. The coarsely crystalline rock is found only within a few hundred yards of the contact but some effect at least is apparent in exposure of the chalk on Onion Creek nearly a mile distant from exposed igneous rock.

In the canyon on Onion Creek and in other localities in the vicinity of Pilot Knob beds of green serpentine-bearing rock are found interbedded in the Austin chalk. These have a finely fragmental texture in part and in part appear as green shales. The materials were derived from igneous rocks and were considered by Hill to be volcanic débris. Some of the beds are fossiliferous and some are gradational into the chalk above. Hill[14] thought that Pilot Knob was a volcano of Cretaceous age which erupted on the sea floor in Austin times and furnished the material now seen on Onion Creek and elsewhere. He recognized that the Austin chalk had been metaphorphosed by the igneous mass of Pilot Knob, but, nevertheless, considered the occurrence to be of Austin age. It is certain that the present Pilot Knob did not erupt the materials found in Onion Creek in beds cut by the intrusion. An earlier center of igneous activity may have been located here, but the present mass is younger than Taylor, and by analogy is thought to be Tertiary in age, as will be shown later. The serpentine beds do represent an earlier igneous activity, as Hill stated, and are similar in this respect to the serpentine conglomerates at Black Waterhole in Uvalde County. The record of two periods of igneous activity are significant geologic features recorded in this locality and both seem evident from the evidence at hand.

SILLS

A sill is a tabular sheet of igneous rock intruded along the bedding planes of sedimentary rocks, the source of supply being from below or from the side. Its feeder may be a dike, stock or other type of intrusive body. The size of sills varies within wide limits, some being many hundred feet thick and miles long, while others are measured in only a few feet in dimensions.

A number of sills are known in the Balcones region and notes on them will be found in the list of occurrences. The greater number are found in Kinney County, but others are known in Uvalde County. Sills have also been encountered in drilling in Travis and Zavala counties, though few details concerning them are known. It is possible that more sills are present than shown in the list for some of the igneous bodies surrounded by wash may be the remnants of such masses uncovered by erosion.

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[14]Hill, R. T., *op. cit.*

Stratigraphically the sills vary considerably. In Kinney County several are found at levels within the Eagle Ford formation. A few are in the Austin, one at the contact of the Austin and Anacacho, and a few within the Anacacho. Nearly all are but remnants of the original sills from which the cover has been removed by erosion, leaving the sill as the protecting cap of a hill. The prominent hills of northern Kinney County were formed in this way. In size the sills are not extensive, none being more than a mile long and a half as wide. Thickness ranges from 15 to 200 feet, though the original thickness cannot, of course, be determined. The greatest thickness is found in the sill at Elm Mountain, Kinney County, where 200 feet of basalt caps the hill. In general the greater thicknesses of the Kinney County sills are found in those to the east suggesting that the source of the igneous rock was in this direction. It is probable that this is the case, because few igneous plugs are known west of the Uvalde County line.

The structural conditions of the sills are similar but are better seen in some exposures than others. Usually an undisturbed sedimentary floor can be determined and this is the feature upon which rests the classification of these bodies as sills. Metamorphism of the sedimentary rocks is negligible in contrast to conditions surrounding those of the plugs. Figure 10, after Udden, is given here to show conditions at Las Moras Mountains north of Brackettville, which may be taken as typical of most of the sills, although minor variations are found.

The age of the sills cannot be accurately determined. All are younger than the formations invaded, and hence are younger than Austin and Anacacho, respectively. The age of these bodies as a group is probably the same as of the plugs and these are thought to be Tertiary as will be shown later.

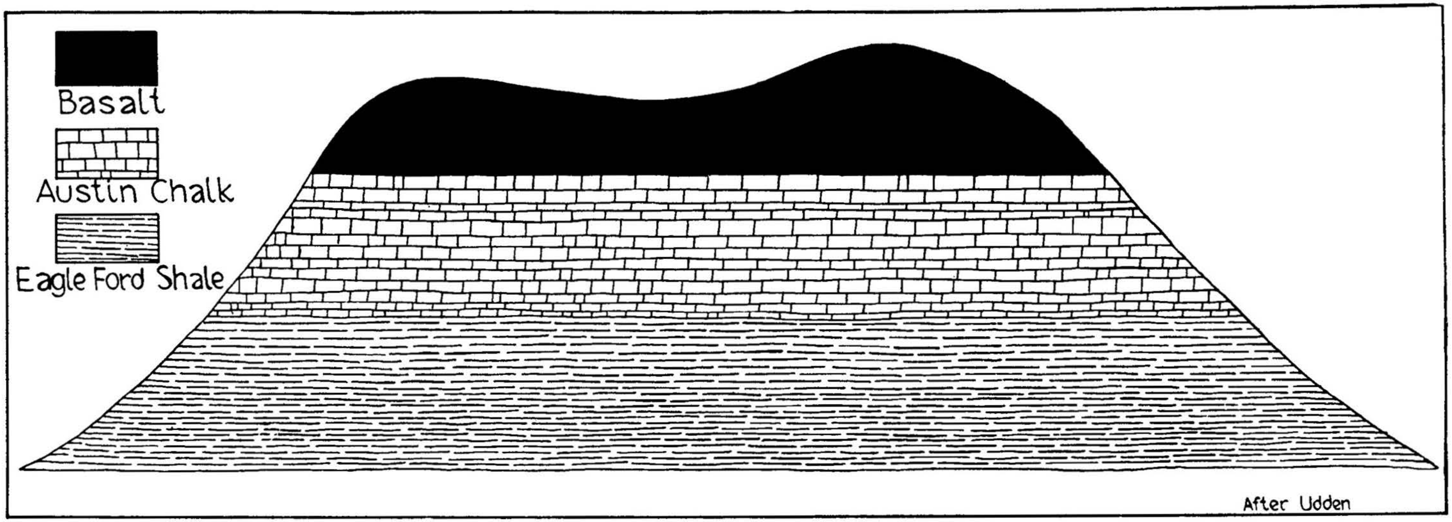

Fig. 10. Cross section of Las Moras Mountain, Kinney County.

DIKES

A dike is an injected wall-like intrusion cutting across the bedding of invaded formations and having a thickness narrow in proportion to its length. The sides are nearly parallel to each other and the dike usually is nearly vertical. The size varies greately, from less than a foot in thickness to many feet and from a few feet in length to many miles.

Very few dikes are known in the Balcones region, the list of occurrences showing the location of those known. Three are known in Bandera County, one in Medina, one in Travis and one in northern Comal County. In addition, it is possible that four isolated bodies of phonolite near Connor's Ranch in Uvalde County are parts of a dike, the relations of which cannot be seen and that an elongate mass of basalt near Knippa is of the same character. All of the known dikes are located on the upthrown side of the Balcones Fault on the Edwards Plateau. The enclosing rocks are Glen Rose limestone in some cases and Edwards in others. The width varies between 5 and 25 feet and traceable length does not exceed one-fourth mile. The dikes stand vertically or nearly so and appear to occupy fault-fissures. Jointing in the limestone is frequently well developed, the joints being parallel to the course of the dikes. Very slight metamorphism accompanied the intrusions.

The location of the dikes on the upthrown side of the fault zone yields some significant information. The exposures are the lowest stratigraphically of all of the igneous rocks. Apparently intrusion of igneous materials at the depth of the Glen Rose limestone was confined to relatively narrow fissures and only at higher levels did the magma expand to form masses like those of Uvalde County.

LACCOLITHS

The type of intrusion known as laccolith was defined in 1877 by Gilbert and further discussed in 1894 by Cross.[15]

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[15]Gilbert, G. K., Report on the Geology of the Henry Mountains, 1877; Cross, W., The Laccolitic Mountain Groups of Colorado, Utah, and Arizona. U. S. Geol. Surv., 14th Ann. Rept., Pt. II, pp. 165–241, 1894.

Additional information is contained in all textbooks of petrology and geology. There seems to be a general agreement that a laccolith is a dome-shaped intrusion with both floor and roof concordant with the bedding planes of the invaded formations, the roof being arched upwards as a result of the intrusion. Ideally the laccolith is a biscuit-shaped mass enclosed within the sedimentary strata. Its floor is a bedding plane, its roof an arch of the beds of a single formation. All gradations between sills on the one hand and dikes on the other are possible. To some of the gradational types special names have been applied, but any intrusive igneous mass confined to a single horizon and retaining the essential character of the perfect form is still regarded as a laccolith.

In the Balcones region no igneous mass is thought to correspond to this definition. Vaughan considered the occurrences at Black Waterhole, Knippa and southwest of Uvalde to be laccoliths, but it is thought that they depart too widely from the definition to permit of such classification. As has been shown, the masses at Knippa and Black Waterhole cut sharply across the bedding and cannot be considered as concordant masses. In addition the floor is not seen. It is difficult to see how they could be classed as laccoliths when these facts are known.

The area southwest of Uvalde conforms more closely to the definition, but here, too, is not thought to contain a laccolith. A map of this locality (Figure 12), from Vaughan, is given in the section on petrology and notes covering it have already been given in the list of occurrences. The area is not a homogeneous unit representing a single concordant intrusion but contains at least five intrusive masses. The central part of the area, composed of olivine-basalt, has been intruded by nephelite-basalt and nephelite-melilite-basalt, the intrusions rising far above the olivine-basalt mass which is exposed at essentially the highest level reached by it. Plainly the later intrusions cannot be classed as laccoliths. The central area superficially conforms more closely to the conditions found in a laccolith but no floor can be seen and the upper surface of the igneous mass is in contact with rock of two formations and accordingly is discordant.

Among the igneous masses of the region flanked by wash and débris it is possible that uncovered laccoliths exist, but the relations are not observable from which a positive identification can be made. In general, judging from the relatively slight erosion the region has suffered since Tertiary times, laccoliths should not be expected for these are masses formed ideally at considerable depth where pressure is high.

AGE OF THE IGNEOUS ROCKS

The exact age of the igneous rocks considered in this report cannot be stated, though it is possible to fix approximately the period or periods of activity which produced certain of the igneous masses and by analogy to relate the others.

Some of the igneous rocks are younger than Pulliam, which is youngest Cretaceous in the Uvalde district, for basalt bodies occur near Wagontop Hill, Uvalde County, showing intrusive relations to the Pulliam. Such occurrences probably belong to early Tertiary times. The other bodies of massive igneous rock are found with intrusive relationships to all of the formations from the Glen Rose to the Anacacho. The exact age of these cannot be determined, but they are also thought to be of early Tertiary age. Undoubtedly the entire series of occurrences of basalts is related in origin and are probably of the same age. Their location is determined by a common structural feature and chemically and mineralogically they are much alike. Since some bodies, as at Wagontop Hill, are of Tertiary age, it is a reasonable inference that the whole group of closely related rocks is of the same age. It may be, of course, that some of the bodies of massive igneous rock intrusive into formations of the Cretaceous are of Cretaceous age, for the only positive relationship is that such are younger than the rock intruded, but there is not a single piece of evidence to show that such an age relationship exists. The interbedded altered igneous rocks are certainly of Cretaceous age as will be shown in the next paragraphs and the statements made above do not apply to them.

It is certain also that igneous rocks were formed in the area as early as Eagle Ford, Austin, and Taylor times. No remnants of solid rock bodies of these ages are known, but the interstratified bodies of serpentine rock found in the Eagle Ford in Uvalde County and in the Austin and Taylor formations, near Austin and elsewhere, are ample evidence for this conclusion. A period of igneous activity as early as Eagle Ford and extending into Austin and Taylor is stated with as much confidence as is the Tertiary age for the massive unaltered rocks.

Two general periods of igneous activity are therefore demonstrated in this area. Based on similarities with other igneous districts, it would not be surprising to learn that igneous activity started in the Eagle Ford time and continued into the Tertiary. There is, however, no evidence to support this, because there are no products of igneous activity related to that considered here to which a date between early Taylor and Tertiary can be assigned. It would not be surprising if such evidence were found in the future and it will likely consist of serpentines, bentonites or tuffs or igneous conglomerate interstratified with rocks above the Austin. When the minute details of the stratigraphy and petrography of the younger Cretaceous formations are known this point can be decided.

It can be predicted, however, that such evidence if found will record igneous activity of smaller magnitude than that shown by the later solid igneous rocks or the earlier serpentines, for if any extensive igneous activity occurred it would have left evidences as striking as the serpentines of the Eagle Ford and Austin times. The accumulation of rocks affording such evidence might be possible only in the case of unconformities general or local, but statements from reliable sources suggest that such breaks in sedimentation are present.

The igneous activity recorded by the massive rocks and here assigned a Tertiary age, is probably early Tertiary. In the area covered by this report and in neighboring territory no intrusive rocks are found in the Tertiary. In middle Tertiary extensive volcanic activity occurred in the lower Coastal Plain as described by T. L. Bailey.[16] No relation between that activity and the rocks here considered is believed possible because the products of the igneous activity are unlike chemically and mineralogically.

The presence of bentonite in the Eagle Ford formation of Texas has long been known, and bentonite has also been recorded from the Taylor and Navarro. Beds of this material form some of the most persistent and widespread horizons of the formation. There may be a relation between this material and the earlier igneous activity previously mentioned, but there is no evidence on the matter and it is unsafe to assume such a relationship because bentonite, a product derived from volcanic ash, may have been deposited far from its original source.

It is concluded that the igneous rocks, altered and unaltered, discussed here record two periods of igneous activity, an earlier one of Eagle Ford or Austin-Taylor age represented by the serpentines, a later one of early Tertiary age by the massive rocks. These may be the beginning and end of a long period of igneous activity, but if so no record of the activity between early Taylor and Tertiary has been found. It is quite likely, however, that such activity did occur, though it was probably less pronounced than that already discussed.

CONTACT METAMORPHISM

The metamorphic effects of the igneous rocks upon the intruded rocks is well shown at a number of localities. Two of the most noteworthy occurrences are Pilot Knob in

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[16]Bailey, T. L., The Gueydan, a New Middle Tertiary Formation from the Southwestern Coastal Plain of Texas. Univ. Texas Bull. 2645, 1927.

Travis County and the large area of igneous rocks southwest of Uvalde in Uvalde County, and some notes on them have already been given. At Pilot Knob the rock intruded is the Austin chalk and the changes brought about consist in recrystallization to a crystalline limestone or marble. This is most pronounced near the igneous rocks, but observed about three-fourths of a mile from the exposed igneous mass. There is no evidence of introduction of foreign material from the magma and only a relatively narrow zone of sediments is affected.

In the area southwest of Uvalde County very interesting metamorphic features are found in blocks of Anacacho limestone included in basalt. A part of these are apparently roof pendants but others are certainly partly engulfed in the basalt. One instance consists of a ledge of limestone 20 feet thick and 200 feet long which is partially buried in basalt. The Anacacho formation at this place is an impure clayey fragmental limestone. The metamorphic effects shown consist of recrystallization of calcium carbonate to form crystalline limestone and a baking with the development of brownish to reddish colors. The actual changes are slight and there has been no introduction of foreign material. There is in this case also no evidence of assimilation of limestone, for the contacts are sharp and the igneous rock near the contact is not modified. In the ledge of limestone mentioned the contact is an actual bedding plane so that assimilation is out of the question.

The most noticeable feature of the metamorphism effected by the igneous rocks and the point to be emphasized in connection with it is the relatively slight changes brought about. Recrystallization of limestones and baking of shaly beds in immediate contact are the principal features. There is no evidence of introduction of foreign material nor of assimilation of sedimentary materials even in the case of xenoliths. It must not be overlooked, however, that the changes produced, slight though they may be in terms of contact metamorphism as seen in some regions, are still definite changes which can be readily recognized and identified. The appearance of the sedimentary rocks affected, especially the limestones, is so different from the ordinary specimens that the changed material is readily recognized.

PETROGRAPHY OF THE IGNEOUS ROCKS

The igneous rocks of the Balcones Fault region are mainly of basaltic types, which exhibit considerable variation, and to a small degree, of phonolitic habit. In general there is a close correspondence chemically and mineralogically among the rocks from one end of the belt in which they occur to the other. The rocks are possibly related to those of southwestern Arkansas on the one hand and of northern Mexico on the other, and with them constitute a petrographic province of considerable extent. In the present report only the Texas occurrences are considered, but it should not be forgotten that these rocks may be but a small part of a large igneous field.

Previous Petrographic Work.—Only a small amount of exact petrographic work has been done on these rocks. This, however, dates back to 1890 when J. F. Kemp described the igneous rock of Pilot Knob, Travis County. In 1893 Osann described basanites from southern Texas which were collected from Mt. Inge, near Uvalde. In the course of the present work no typical basanites have been found and Cross, in the Uvalde folio, makes the same observation. The rocks collected by T. W. Vaughan during his work in the Uvalde district were described by Whitman Cross in Folio 64 of the United States Geological Survey. Free use has been made of the published data and it has served as a guide in extending the studies of the igneous rocks to greater detail. In the main, the classifications of Cross are accepted. A few more occurrences in the Uvalde district have been found and minor types have been separated.

In addition to the work mentioned above occasional brief notes on the igneous rocks have appeared in various publications. These have been of a geologic rather than a petrographic nature and need not be considered here.

Chemical Analyses.—Only a limited number of chemical analyses are available for the present study. These have been secured from several sources and eight are new anlyses made especially for this work in the Bureau of Industrial Chemistry, University of Texas. Superior analyses appearing in Washington's tables have been quoted along with the norms and normative classifications calculated by him. In the case of new analyses the norms have been calculated by the writer. It is to be regretted that more analyses are not available.

CLASSIFICATION

For the purpose of petrographic description the rocks considered here will be classified without regard to their modes of occurrence. This is done because rocks essentially similar occur in several manners. In the igneous plugs are found phonolite, nephelite-basalt, nephelite-melilite-basalt and olivine-basalt, while on the other hand nephelite basalt occurs in dikes, sills, and plugs. In the present section of the report geologic occurrence is subordinate in importance to character and composition.

In all cases in which superior chemical analyses are available the rocks are classified in both the qualitative and C. I. P. W. systems of classification. While this can be done in only a relatively few instances it is believed that there are sufficient analyses to classify representatives of all of the types present, except possibly the limburgitic rocks. In the petrographic descriptions a number of the rock names used are defined. This is done because of the lack of uniformity in usage of the terms and to insure a better understanding of the report. Below appear two tables showing the types of rock found in the region, classed in the two systems of classification. These are followed by the petrographic descriptions.

Balcones Fault Zone Rocks in Qualitative Classification

Basaltic Rocks	Limburgite Nephelite-Melilite basalt Nephelite basalt Olivine basalt
Gabbro	
Phonolitic Rocks	Uvalde Phonolite Nephelinite Phonolite
Pegmatite	

Balcones Fault Zone Rocks in C. I. P. W. Classification

CLASS	ORDER	SECTION	RANG	SUBRANG
Dosalane	Germanare		Hessase	Hessose
			Laurdalase	Laurdalose
	Norgare		Essexase	Essexose
	Italare		Lujavrase	Lujavrose
Salfemane	Portugare		Limburgase	Limburgose
	Gallare		Camptonase	Camptonose
Dofemane	Hungarare	4 No Name	2 No Name	2 No Name
	Scotare	Texiare	Uvaldase	Uvaldose

BASALTS

Basalt defined.—The term basalt has been used in a number of applications, and there are several varieties of basalt recognized. In view of these facts, it has been thought wise to define the rock names of basaltic rocks used in this report. *Basalt* includes igneous rock of a lava flow or minor intrusion; often vesicular or amygdaloidal, porphyritic or non-porphyritic and usually having in part at least an aphanitic texture. Mineralogically the rock is composed essentially of plagioclase (at least as calcic as labradorite) and pyroxene with or without a glassy groundmass. If olivine is present the rock is *olivine-basalt*. In some cases plagioclase is absent and nephelite or melilite are found instead. Such rocks are *nephelite-basalt* or *melilite-basalt.* If both nephelite and melilite are present the rock is called *nephelite-melilite-basalt.* If the rock is composed almost entirely of augite and olivine it becomes *limburgite.* The following varieties of basalt are recognized in the present work: *Olivine-basalt, nephelite-basalt, nephelite-melilite-basalt,* and *limburgite.*

OLIVINE-BASALT

Occurrences.—Olivine-basalt occurs in a number of localities in the region. Reference to the maps and list of occurrences accompanying this report will show the various exposures. The more important ones are Pinto Mountain in Kinney County, Green Mountain in Uvalde County, Palmer Hill in Kinney County, Mumme's Ranch in Medina County, King's Ranch in Medina County, Round Mountain in Uvalde County, Tom Nunn's Hill in Uvalde County, and Mustang Waterhole, north of Cline, in Uvalde County. Exact locations of these and other occurrences are given in the list of occurrences.

In the description of olivine-basalt, Green Mountain is taken as the type. This is done because a chemical analysis of the rock is available and because the rock is representative. After the type has been described variations from it as seen from place to place will be mentioned. It is not thought necessary to include complete descriptions of all the olivine-basalts which differ only slightly from the type.

Megascopic characters.—The olivine-basalt found at Green Mountain is dark gray, almost black in color, and is holocrystalline even to the unaided eye. Grains of olivine, augite, and plagioclase feldspar are recognized and the texture appears fairly even-granular.

Microscopic characters.—Under the microscope the rock is seen to be holocrystalline. The fabric is intermediate between seriate intersertal and seriate porphyroid. The minerals present are olivine, augite, labradorite, magnetite, biotite, apatite and serpentine. The larger crystals of the rock are olivine, and though they cannot be called phenocrysts, are distinctly larger than crystals of the other minerals.

Olivine is very abundant in the rocks, constituting about one-fourth of the mass. It occurs in colorless anhedral grains greatly jointed and cracked. Individual crystals attain dimensions of 1.5 mm. Only a slight alteration to serpentine is noticed.

Augite is abundantly present as small prismatic crystals with subhedral outlines. The color is gray with a suggestion of violet.

Labradorite occurs as prominent lath-shaped crystals up to .6 mm. in length.

Magnetite is present in fair abundance. The occurrence of the mineral is unusual. The grains are large and irregular in shape, attaining dimensions of 2 mm. The dimensions are variable, smaller grains being nearly equidimensional, while the larger ones are usually elongate. The mineral is intergrown with feldspar and augite after a pattern suggesting graphic texture. This is probably due to inclusions of feldspar and augite rather than a true intergrowth. The magnetite is younger than olivine and probably younger than feldspar and augite in the rock.

Biotite is commonly but not abundantly present. It occurs as intergrowths with augite, as separate flakes in the general mass of the rock, and as a rim surrounding magnetite grains. This latter occurrence is unusual. It suggests a reaction rim between the two minerals.

The olivine-basalt here described shows rather unusual features. The order of separation of the minerals is not the customary one, since olivine was first, labradorite and augite next, followed by magnetite, which in turn was followed by biotite. Probably overlap existed in the periods of separation of the minerals but the general order is believed to be as stated above. One correction might be made depending upon the character of the occurrence of magnetite associated with feldspar and labradorite. If the structures present are intergrowths, the three minerals crystallized together. It is probable that the occurrence is simply a modification of poikilitic fabric in which magnetite acts as the oikocryst, feldspar and magnetite being chadacrysts.

Chemical composition.—Chemical analyses are available not only for the olivine-basalt from Green Mountain but also for rocks from Pinto Mountain in Kinney County and Mustang Waterhole in Uvalde County. Since the basalts differ chemically and belong to three groups in the normative classification, three tables of analyses of related rocks are given. In each table analysis No. 1 is of the Texas basalt, while the other analyses are given in comparison. Unless otherwise noted the analyses and names of related rocks in these and other tables of the report are taken from Washington's tables, to which further reference is not deemed necessary.

Analyses of Green Mountain Basalt and Related Rocks

	1	2	3	4	5	6	7	8
SiO_2	45.30	46.33	45.88	46.28	42.58	43.30	51.41	49.06
Al_2O_3	12.66	14.46	12.60	14.18	14.68	14.07	13.70	15.70
Fe_2O_3	2.93	2.22	3.47	3.79	5.96	5.53	4.36	5.38
FeO	10.54	11.09	11.03	7.34	11.29	7.17	6.08	6.37
MgO	8.39	4.89	6.42	10.82	6.32	9.62	6.43	6.17
CaO	11.86	10.58	9.97	9.88	10.10	10.87	11.61	8.95
Na_2O	2.65	2.83	3.48	2.58	3.39	2.41	3.88	3.11
K_2O	0.66	1.31	1.11	1.01	0.64	1.12	0.55	1.52
H_2O+	1.79	3.23	3.17	1.66	1.55	2.52	1.89	1.62
H_2O-			0.49	0.31				
TiO_2	1.68	2.52	1.62	2.06	3.49	2.83	0.88	1.36
P_2O_5	0.89	0.30	0.11	0.44	0.22	0.65	0.31	0.45
MnO	------	------	0.25	0.09	0.13	------	------	0.31
Incl	------	0.63	0.15	------	------	0.10	------	------
	99.35	100.39	99.75	100.49	100.35	100.19	100.79	100.00

1. Olivine-basalt from Green Mountain, Uvalde County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.

2. Diabase, Forstort Winde, near Rübeland, Harz.
3. Diabase, Schönbach, near Herborn, Hesse-Nassua.
4. Basalt, Redside, East Lothian, Scotland.
5. Camptonite, Golentz, Lausitz.
6. Basalt, Ribeiria Frio, Madeira.
7. Diabase, Kohlhau, Lausitz.
8. Average basalt of Daly. Daly, R. A., Igneous Rocks and Their Origin, p. 27, 1914.

Analyses of Pinto Mountain Basalt and Related Rocks

	1	2	3	4	5	6	7
SiO_2	45.11	47.51	45.48	46.71	50.12	47.91	47.31
Al_2O_3	12.44	15.52	11.87	12.46	15.70	14.26	16.66
Fe_2O_3	2.67	3.25	1.98	3.00	1.42	1.65	2.67
FeO	9.36	5.96	9.87	9.03	6.89	7.80	6.55
MgO	11.56	5.85	13.28	9.56	9.50	10.83	8.20
CaO	10.61	14.05	10.97	11.61	11.30	9.60	9.61
Na_2O	3.05	3.21	2.21	3.10	2.91	3.01	3.40
K_2O	1.01	1.32	0.77	1.06	1.07	1.89	1.44
H_2O+	0.78	1.89	0.74	1.11	1.03	0.37	2.88
H_2O-	0.16		0.23		0.21		
TiO_2	2.34	0.51	1.90	1.74	0.55	2.70	1.33
CO_2	------	------	------	------	------	------	------
P_2O_5	0.51	0.89	0.25	0.33	------	------	------
MnO	0.22	------	0.16	------	------	------	------
Incl	0.20	------	0.23	------	0.14	------	------
Sum.	100.02	99.96	99.94	99.76	100.84	100.02	100.05

1. Basalt Pinto Mountain, Kinney County, Texas. W. F. Hillebrand, analyst. U. S. Geol. Surv. Bull. 168, p. 61, 1900.
2. Gabbro, Green Mountain, Uvalde County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.
3. Basalt Makaweli Canyon, Kauai, Hawaiian Islands.
4. Limburgite, Adolph Friedrich Cone, Lake Kivu District, German East Africa.
5. Diabase, O'Brien Mine, Cobalt, Ontario.
6. Basalt, American Flat Creek, Washoe, Nevada.
7. Gabbro-diorite, Val Rosegg, Bernina District Switzerland.

Analyses of Mustang Waterhole Basalt and Related Rocks

	1	2	3	4	5	6
SiO_2	50.00	48.24	49.25	51.08	48.90	46.27
Al_2O_3	16.93	17.41	17.47	19.77	18.90	18.43
Fe_2O_3	1.01	5.62	3.33	trace	0.30	3.98
FeO	10.40	5.79	6.77	3.60	9.00	8.22
MgO	1.50	7.08	3.75	4.57	6.00	3.75
CaO	12.94	12.27	11.09	16.03	12.20	12.33
Na_2O	2.96	2.44	4.45	2.56	3.00	2.58
K_2O	0.88	1.01	1.42	0.28	0.30	0.96
H_2O+	1.23	0.60	0.18	0.65	0.50	2.98
H_2O-	0.25			0.15		
TiO_2	1.50	......	1.74	0.45	1.40	0.33
P_2O_5	trace	......	0.81	0.14	......	......
MnO	......	......	......	0.09	......	......
Incl	......	......	......	0.32	......	......
Sum.	99.60	100.46	100.26	99.69	100.50	99.83

1. Olivine-basalt from Mustang Waterhole, Uvalde County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.
2. Basalt, Station 168, 2414 meters deep, 114 miles northeast of New Amsterdam.
3. Basalt, Valle Del Petrolo, Mount Etna, Sicily.
4. Gabbro, Hedley District, British Columbia.
5. Basalt, Gubbet Karab, French Somali.
6. Labradorite (Basalt) Avirons, Reunion Island.

The general characters of the three olivine basalts are similar. Silica is not more than 50 per cent. Alumina is more than 10 per cent and lime exceeds soda and potash combined. Titanium oxide is fairly abundant. The greatest variation is seen in magnesia and iron, part of which may be due to analytical errors. Compared with related rocks the three Texas basalts are fairly representative of their respective groups in which rocks from widely separated regions are included.

Classification.—In the prevailing system of classification these rocks are olivine-basalts. All contain olivine, augite, and labradorite as the significant minerals. The norms of the basalts from Green Mountain, Pinto Mountain, and

Mustang Waterhole, with those of the related rocks, in the following three tables are arranged as the tables of chemical analyses. From the data calculated the Green Mountain basalt is designated *camptonose*, that from Pinto Mountain is *limburgose*, and the Mustang Waterhole rock is *hessose*. No. 8 of the first table, the "average basalt" of Daly, is *auvergnose* close to *camptonose* and *limburgose* and with them comprises the most abundant group of 613 basaltic rocks listed in Washington's tables. The basalts from Green Mountain and Pinto Mountain can be considered as average basalts, but the rock from Mustang Waterhole is of a more acidic character.

Norms of Green Mountain Basalt and Related Rocks

	1	2	3	4	5	6	7	8
or	3.89	7.78	6.67	6.12	3.89	6.67	3.34	8.90
ab	18.34	22.01	20.44	21.48	18.34	16.24	32.49	26.20
an	21.13	23.07	15.27	23.91	22.80	24.19	18.07	24.46
ne	1.99	0.85	4.83	0.28	5.68	2.27	0.28	------
di	26.77	22.88	27.46	17.92	20.62	19.98	31.69	13.81
ol	16.10	11.12	12.65	18.29	11.58	13.34	5.00	2.01
mt	4.18	3.25	5.10	5.57	8.82	7.89	6.50	7.89
il	3.04	4.26	3.04	3.95	6.69	5.32	1.17	2.58
ap	2.02	0.67	0.34	1.01	0.67	1.68	------	1.39
hy	------	------	------	------	------	------	------	11.54

Class: $\frac{\text{Sal}}{\text{Fem}} = \frac{45.35}{52.11} = .8 = \text{III, salfemane}$

Order: $\frac{\text{L}}{\text{F}} = \frac{1.99}{43.36} = .04 = 5\text{, gallare}$

Rang: $\frac{K_2O' \; Na_2O'}{CaO'} = \frac{49}{76} = .64 = 3\text{, camptonase}$

Subrang: $\frac{K_2O'}{Na_2O'} = \frac{7}{42} = .16 = 4\text{, camptonose}$

Symbols of the related rocks are as follows:

2. III.5.3″.4.
3. III.5(6).3.4″.
4. ″III.5.3.4(4).
5. III.5(6).3″.(4)5.
6. III.5.(3)4.4.
7. III.5.3.″5.
8. II.5.3″.4.

Norms of Pinto Mountain Basalt and Related Rocks

	1	2	3	4	5	6	7
or	6.12	7.78	4.45	6.67	6.67	11.12	8.90
ab	13.10	12.05	13.36	15.20	19.91	15.72	19.30
an	17.24	23.91	20.57	16.68	26.41	20.02	25.58
ne	6.82	8.24	2.70	5.96	2.56	4.83	5.11
di	26.13	35.25	25.70	31.39	23.97	21.99	17.57
ol	20.05	3.70	24.73	14.35	17.65	17.96	14.22
mt	3.94	5.10	3.02	3.34	2.07	2.32	3.71
il	4.41	0.91	3.65	------	1.06	5.17	2.58
ap	1.34	2.02	0.67	0.67	------	------	------
hm	------	------	------	------	------	------	------

Class: $\frac{\text{Sal}}{\text{Fem}} = \frac{43.30}{55.87} = .77 = $ "III, salfemane

Order: $\frac{\text{L}}{\text{F}} = \frac{6.82}{36.46} = — .18 = 6$, portugare

Rang: $\frac{K_2O' \; Na_2O'}{CaO'} = \frac{60}{62} = .96 = 3$, limburgase

Subrang: $\frac{K_2O'}{Na_2O'} = \frac{11}{49} = .26 = 4$, limburgose

Symbols of the related rocks are as follows:

2. III(5)6.3".4.
3. III".5".(3)4.4".
4. II.(5)6.3.4.
5. (II)III.5.3(4).4.
6. III.5".3.4.
7. (II)III.5".3.4.

Norms of Mustang Waterhole Basalt and Related Rocks

	1	2	3	4	5	6
or	5.56	6.12	8.34	1.67	1.67	5.56
ab	24.63	20.44	26.72	21.48	25.15	22.01
an	30.30	33.64	23.35	41.70	37.25	35.86
di	29.50	22.02	21.36	29.95	16.97	19.10
ol	1.43	9.20	4.15	0.80	14.62	4.73
mt	1.39	8.12	4.87	------	0.46	5.80
il	2.89	------	3.34	0.91	2.74	5.62
hy	2.52	0.43	------	------	0.56	0.43
ap	------	------	2.02	0.34	------	0.67
ne	------	------	5.96	------	------	------

Class: $\dfrac{\text{Sal}}{\text{Fem}} = \dfrac{60.49}{37.73} = 1.6 = \text{II, dosalane}$

Order: $\dfrac{\text{QL}}{\text{F}} = \dfrac{0}{60.49} = \infty = 5, \text{ germanare}$

Rang: $\dfrac{K_2O' \ Na_2O'}{CaO'} = \dfrac{57}{109} = .52 = 4, \text{ hessase}$

Subrang: $\dfrac{K_2O'}{Na_2O'} = \dfrac{10}{47} = .4 = 4, \text{ hessose}$

Symbols of the related rocks are as follows:

2. II(III).5.4.4.
3. II(III).5″.3.4″.
4. II″.5.4.″5.
5. II(III).5.4.5.
6. II(III).5.4.4.

Variations.—Variations among the olivine-basalts are mainly along textural lines, though a slight variation is present among the minerals constituting the rock. Thus biotite is present in some specimens but absent in others, apatite likewise may or may not be present. There is also variation in the relative amounts of the constituent minerals. Olivine, augite, feldspar and magnetite are present in all specimens but their abundance varies. Olivine is very abundant in the basalt at Green Mountain, while it is much less abundant at the locality 8 miles south of Cline. The same type of variation holds for the augite, magnetite and feldspar. With variation, the rocks approach other species but in no instance are rocks included here which do not belong in the group.

The texture of fabrics present among the olivine-basalts are of two general types with gradations between. One type, possibly the most common, has already been described for the rock from Green Mountain. This is medium-grained with no great contrast in size among grains of the different minerals. Magnetite in this type of fabric is present in large grains, being comparable in size with olivine and generally larger than augite or feldspar. The fabric is close to seriate porphyroid. The second type of fabric is a true seriate porphyritic type. Phenocrysts of olivine and augite (with great contrast in size) are imbedded in a groundmass of augite, feldspar and magnetite. Magnetite, instead of occurring as larger irregular grains comparatively few in number, is present as countless minute grains with euhedral habit. There is probably some difference in the order of crystallization of the two fabrics, but this has not been determined.

The two types of fabric are in great contrast. Plate II shows photomicrographs with the same magnification of the two textures. However, gradation exists among the fabrics present for certain specimens show fabrics slightly finer than the Green Mountain type, while others show fabrics slightly coarser than the seriate porphyritic extreme mentioned in the previous paragraph.

Although analyses are not available for all of the olivine-basalts studied, it is evident that most of the specimens correspond closely to the analyses given. The rather slight divergence in amounts and kinds of minerals render it unlikely that the rocks would show great chemical variation. It is believed that all of these rocks would fall into nearly the same classification in the quantitative system. There might be as much difference as already shown in the camptonose and limburgose but these two normative types are very close together.

NEPHELITE-BASALT

Nephelite-basalt is represented by numerous occurrences in the district covered by this report. Reference to the detailed list of occurrences will show the location of all known bodies of nephelite-basalt. Noteworthy among these are: Knippa, Uvalde County; Turkey Mountain, Kinney County; Asphalt Mountain, Uvalde County; Las Moras Mountain, Kinney County, and near Turkey Foot, west of Austin.

Included under the term *nephelite-basalt* are all of the basaltic rocks that contain notable amounts of nephelite and that lack melilite and feldspar. Rocks that contain melilite along with nephelite are classed as *nephelite-melilite-basalts* and described separately, though chemical analyses and norms of the two types are grouped together. The limitation of the term nephelite-basalt is arbitrary since gradation exists among the nephelite-bearing rocks encountered. By decrease in the amount of nephelite the rock limburgite is approached, while the presence of determinable melilite along with the nephelite places the rock among the nephelite-melilite-basalts. Gradation is possible to the extent that melilite becomes more important than nephelite. Such rocks approach melilite-basalt. A few rocks were found that contained negligible amounts of nephelite and an abundance of melilite.

In the following discussion of nephelite-basalt specimens from a locality 1 mile north of Yucca Siding, Uvalde County, are described in detail. The specimens selected are believed to bear an average relationship among the nephelite-basalts known in the district. Furthermore, these specimens have not been described up to the present time, since the locality is now shown on the geologic maps accompanying the Uvalde Folio. Variation among nephelite-basalts as contrasted with the locality mentioned are noted.

Megascopic characters.—A dark gray, almost black rock, with an aphanatic groundmass containing numerous phenocrysts up to 3 mm. in length. Recognizable minerals include olivine and occasional grains of augite. Oxidized surfaces are grayish-brown and are covered with minute pits from which the phenocrysts have been removed by weathering.

Microscopic characters.—The fabric is seriate-porphyritic. The groundmass is composed of augite, magnetite and nephelite, while the phenocrysts are mainly olivine with a few of augite. Small amounts of a spinel-like mineral, biotite, serpentine and a fibrous zeolitic mineral are also present. The order of crystallization among the minerals is fairly definite. Two generations of magnetite are present, one of these in small amounts along with spinel crystallized first. Next was olivine, then came the second generation of magnetite along with augite. Nephelite crystallized last. The position of biotite in this series could not be determined.

Olivine is present in abundance as colorless phenocrysts, varying in size from grains slightly larger than those of the groundmass up to dimensions of 3 mm. An occasional euhedral crystal was observed, but most are subhedral or anhedral. Many of the olivine crystals show a slight degree of alteration to serpentine. Corroded crystals are abundant, the embayed areas being filled with the minerals of the groundmass. The percentage of olivine in a uniform field of the sections is estimated to be ten.

Augite is restricted almost entirely to the groundmass. The few phenocrysts of augite are subhedral in development, of grayish-violet color and faintly pheochroic. The augite of the ground occurs as stubby laths or prismatic crystals, many of which are euhedral. The color is grayish-violet, but the violet shade is weaker than in the augite phenocrysts. In the augite of the groundmass and also among the phenocrysts zonal structure is common, either in regular zones or after the "hour glass structure." No chemical analyses of the augite from the rock north of Yucca Siding are available, but an anlysis of augite from the nephelite-basalt of Black Mountain not far away is given below.[17]

The augite of the two rocks is similar under the microscope, so that the analysis probably represents fairly well the augite from the rock under discussion.

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[17]Clarke, F. W., Analyses of Rocks, Laboratory of the U. S. Geological Survey, 1880–1900. U. S. Geol. Surv. Bull. 168, p. 65, 1900.

SiO_2	45.23
Al_2O_3	7.73
Fe_2O_3	2.95
FeO	4.07
MgO	12.85
CaO	23.37
Na_2O	.47
K_2O	.12
H_2O+ / H_2O-	.37
TiO_2	4.28
NiO_2	.05
MnO	.07
Li_2O	trace
	100.96

The percentage of titanium oxide shown is noteworthy, being much more than for the whole rock which is 2.70.[18] Apparently the titanium of the nephelite-basalt is concentrated in augite. Since titanium rich augites are usually violet colored, it is probable that the augite of the phenocrysts is slightly richer in titanium than the augite of the groundmass since there is a distinct difference in color.

Nephelite is abundant in the sections, comprising more than one-third of the groundmass. It occurs as colorless anhedral grains that form a matrix for the other minerals. The distribution of nephelite in the rock is not uniform, for in some parts it is much more abundant than others. Acting as a matrix for the other minerals it was the last component to crystallize.

Magnetite is abundant in the groundmass. It occurs as anhedral to euhedral minute, black opaque grains. A very small amount of the mineral occurs as inclusions in olivine phenocrysts. The magnetite of the ground crystallized approximately along with augite subsequent to olivine and before nephelite. Magnetite inclusions in olivine crystallized before olivine and belong to the same generations as the spinel-like mineral described below.

[18]Clarke, F. W., *op. cit.*, p. 63.

Included in the olivine phenocrysts, and to a slight extent in the groundmass, is an exceedingly small amount of an isotropic reddish-brown mineral. It is nearly opaque and shows euhedral outlines of isometric crystals. This is believed to be either perovskite or one of the spinel minerals, possibly picotite. The mineral is present in such small crystals and in such small quantities that positive identification could not be made. It will be mentioned simply as a spinel-like mineral. It represents the first product of crystallization.

Biotite was seen as one or two reddish-brown pleochric flakes. A few minute prisms of apatite were noted.

An exceedingly small amount of fibrous yellowish to transparent material occurs in the rock as an alteration of nephelite. This is apparently of zeolitic nature.

Chemical composition.—In the following table analyses of nephelite-basalt and related rocks are given. Analyses of nephelite-melilite-basalt from the Balcones region are also included. The first three analyses are quite similar and the analyses listed for comparison are related to these. No. 4, the rock from Black Waterhole, is totally different and no analyses has been found at all similar to the one quoted.

Analyses of Nephelite Basalt, Nephelite-Melilite Basalt and Related Rocks

	1	2	3	4	5	6	7	8	9
SiO_2	40.32	39.92	37.96	37.42	38.74	35.84	40.95	39.75	39.87
Al_2O_3	9.46	8.60	10.14	7.96	11.30	10.48	15.37	13.34	13.58
Fe_2O_3	4.75	4.40	3.69	4.86	4.28	7.25	6.36	4.00	6.71
FeO	7.48	8.00	7.59	6.42	7.71	6.62	4.38	8.55	6.43
MgO	18.12	20.17	14.69	16.00	11.97	12.95	10.46	14.81	10.46
CaO	10.55	10.68	16.28	13.87	14.43	10.90	11.67	10.90	12.36
Na_2O	2.62	1.91	2.18	6.87	3.02	3.53	3.97	3.41	3.85
K_2O	1.10	1.03	0.69	trace	1.92	1.51	1.26	0.75	1.87
H_2O+	1.25	1.45	1.82	2.65	1.28	......	3.93	1.26	2.22
H_2O-	0.57	0.43	0.39	0.39	0.60	......	0.86		
TiO_2	2.66	2.70	2.93	3.20	3.30	8.85	0.25	3.42	1.50
P_2O_5	0.68	0.51	1.13	trace	1.77	......	0.09	0.17	0.94
MnO	0.25	0.24	0.22	......	......	......	......	......	0.21
Cr_2O_3	......	......	......	......	......	2.84	......	......	......
Incl.	0.28	0.41	0.42	......	......	......	0.29	......	......
Sum.	100.09	100.45	100.13	99.64	100.32	100.77	99.84	100.36	100.00

1. Nephelite-basalt, Tom Nunn's Hill, Uvalde County, Texas. W. F. Hillebrand, analyst. W. Cross, U. S. Geol. Surv. Bull. 168, p. 62, 1900.
2. Nephelite-basalt, Black Mountain, Uvalde County, Texas. W. F. Hillebrand, analyst. W. Cross, U. S. Geol. Surv. Bull. 168, p. 63, 1900.
3. Nephelite-melilite-basalt, near Uvalde, Uvalde County, Texas. W. F. Hillebrand, analyst. W. Cross, U. S. Geol. Surv. Bull. 168, p. 63, 1900.
4. Nephelite-melilite-basalt, Black Waterhole, Uvalde County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.
5. Nephelinite, Mount Tsiafajavona, Madagascar.
6. Melilite-basalt, Randen, Hegau, Baden.
7. Limburgite, Cerro Tacumber, Paraguay.
8. Nephelinite, Rougiero, Var, France.
9. Average nephelite-basalt, Daly, R. A., Igneous Rocks and Their Origin, p. 33, 1913.

No analysis of the rock from near Yucca Siding is available. However, analyses of two rocks from localities in the same region were included and can be used instead. These analyses show that the nephelite-basalt found in Tom Nunn's Hill and from Black Mountain are similar. Silica is about 40 per cent, alumina less than 10 per cent, magnesia nearly 20, and lime much more abundant than soda and potash combined. Titanium oxide is fairly prominent. Comparison with related rocks of the same normative classification shows that the nephelite-basalts are in an average position with relation to the others. However, these nephelite-basalts differ from the average nephelite-basalt of Daly, shown in No. 9 of the table. Of 27 nephelite-basalt (from Washington's tables) in the Quantitative System, only 17.51 per cent fall into the class *Uvaldose*.

Classification.—The nephelite-basalt described above can properly be given this name in the microscopic classification of rocks. Olivine, augite, and abundant nephelite are the essential minerals which determine its position. As will be seen later, there is considerable variation among the nephelite-basalts.

Norms of nephelite-basalt from Big Mountain and Tom Nunn's Hill, Uvalde County, and of related rocks are shown in the following table. The nephelite-basalts are designated *Uvaldose* in the quantitative classification.

Norms of Nephelite-Basalt, Nephelite-Melilite-Basalt, and Related Rocks

	1	2	3	4	5	6	7	8	9
or	3.89	......	......	......	......	2.22	2.22	......	1.67
an	11.12	11.95	15.85	......	12.23	8.62	19.74	18.90	20.02
lc	2.18	4.80	3.05	......	8.72	5.23	4.36	3.49	......
ne	11.93	8.52	9.94	21.87	13.63	15.90	18.46	15.62	......
di	28.68	28.24	22.45	......	27.67	27.22	30.13	24.83	30.85
ol	26.75	31.27	23.34	31.88	15.64	13.86	10.20	22.78	24.19
mt	6.76	6.26	5.34	2.32	6.26	......	9.28	5.80	9.05
il	5.02	5.17	5.32	6.08	6.23	11.25	0.46	6.54	1.98
ap	1.68	1.34	2.69	......	4.03	......	......	0.34	......
cs	......	0.52	9.03	......	4.05	......	......	0.95	......
ack	......	......	......	23.62	......	......	......	......	......
hm	......	......	......	......	......	7.25	......	......	......
cm	......	......	......	......	......	3.74	......	......	......
pf	......	......	......	......	......	5.03	......	......	......
ns	......	......	......	1.59	......	......	......	......	......
ab	......	......	......	......	......	......	......	......	11.00
ac	......	......	......	9.24	......	......	......	......	......

(1)

Class: $\dfrac{\text{Sal}}{\text{Fem}} = \dfrac{29.12}{72.89} = .39 = \text{IV},''$ dofemane

Order: $\dfrac{\text{P O}}{\text{M}} = \dfrac{55.43}{11.78} = 4.7 = 2,$ scotare

Section: $\dfrac{\text{P}}{\text{O}} = \dfrac{28.68}{26.75} = 1.01 = 3,$ texiare

Rang: $\dfrac{(\text{MgFe})\text{O}}{\text{CaO}''} = \dfrac{557}{143} = 3.38 = 2,$ uvaldase

Subrang: $\dfrac{\text{MgO}}{\text{FeO}} = \dfrac{453}{104} = 4.3 = 2,$ uvaldose

(2)

Class: $\frac{\text{Sal}}{\text{Fem}} = \frac{25.27}{72.80} = .34 = \text{IV}''$, dofemane

Order: $\frac{\text{P O}}{\text{M}} = \frac{59.51}{11.43} = 5.1 = 2$, scotare

Section: $\frac{\text{P}}{\text{O}} = \frac{28.24}{34.27} = .82 = 3$, texiare

Rang: $\frac{\text{(MgFe)O}}{\text{CaO}''} = \frac{618}{158} = 3.2 = 2$, uvaldase

Subrang: $\frac{\text{MgO}}{\text{FeO}} = \frac{504}{114} = 4.4 = 2$, uvaldose

(3)

Class: $\frac{\text{Sal}}{\text{Fem}} = \frac{28.79}{68.17} = .42 = \text{IV}$, dofemane

Order: $\frac{\text{P O}}{\text{M}} = \frac{45.97}{10.66} = 4.2 = 2$, scotare

Section: $\frac{\text{P}}{\text{O}} = \frac{22.45}{23.34} = .96 = 3$, texiare

Rang: $\frac{\text{(MgFe)O}}{\text{CaO}''} = \frac{435}{234} = 1.9 = 2$, uvaldase

Subrang: $\frac{\text{MgO}}{\text{FeO}} = \frac{365}{70} = 5.2 = 2$, uvaldose

(4)

Class: $\frac{\text{Sal}}{\text{Fem}} = \frac{21.87}{77.77} = .27 = \text{IV}$, dofemane

Order: $\frac{\text{P O}}{\text{M}} = \frac{64.74}{8.40} = 7.7 = 1$, hungarare

Section: $\frac{P}{O} = \frac{9.24}{55.50} = 1.16 = 4$, no name

Rang: $\frac{MgO+FeO}{CaO''} = \frac{489}{246} = 1.9 = 2$, no name

Subrang: $\frac{MgO}{FeO} = \frac{400}{89} = 4.6 = 4$, no name

5. (III) IV.2."3.(2).
6. (III) IV.(2)3.2".2.2.
7. III.7.3.3.4".
8. III(IV).7.3.4(5).
9. "IV."2.3.2.2.

Variations.—Variations among the nephelite-basalts are of both a mineralogic and textural nature. The variation in texture is due largely to a variation in habit of the nephelite. In specimens described above nephelite formed a definite matrix for the other minerals. In specimens from other localities the nephelite is present as subhedral crystals giving an entirely different textural aspect. Further textural variation is due to the variation in amount of olivine phenocrysts, the abundance of which varies between wide limits. The fabrics present probably fall into three classes, seriate porphyritic, seriate intersertal, and seriate porphyroid. Of these the seriate porphyritic is by far most common. Plate III illustrates textural variations.

Mineralogical variations seen are mainly in relative amounts of the various minerals. Biotite is found in a few instances as is apatite, and these are purely accessory in character. Zeolitic material, an alteration of nephelite is present in some specimens. The main variations, however, are in the amounts of two of the essential minerals. Nephelite varies between rather wide limits, being abundant in some localities and sparingly present in others. Furthermore, olivine also varies generally in amount. Augite, to the contrary, is abundant in all specimens.

It can be seen that the rocks classed as nephelite-basalt are those of a somewhat varied nature. However, this is on a microscopic scale. All of the rocks contain nephelite, olivine and augite, and are thus, properly speaking, nephelite-basalts. The variation simply illustrates the gradation so common among igneous rocks.

NEPHELITE-MELILITE-BASALT

Rocks corresponding to this classification are present in the area considered here in fair abundance. They are found in a number of localities in the Uvalde district. Reference to the table of localities will give the exact locations in each case. Among the more noteworthy occurrences are Taylor Hills, Uvalde County; Tom Nunn's Ranch, Uvalde County; Black Waterhole, Uvalde County, and Allen Hill, Uvalde County.

The rocks here called nephelite-melilite-basalt differ from the nephelite-basalts only by the presence of determinable amounts of the mineral melilite, a complex silicate of calcium and magnesium. Through variation in the amount of melilite these rocks approach melilite-basalts on the one hand and limburgite on the other. Chemical anlyses available and norms of these rocks are listed with the nephelite-basalts, since they fall generally in the same normative classification.

The description which follows is of specimens from an occurrence on the Tom Nunn Ranch southwest of Uvalde. Variations of a minor sort in other localities are mentioned afterward.

Megascopic characters.—The rock from the Tom Nunn Ranch is dark gray, almost black, with an aphanitic groundmass in which are imbedded numerous phenocrysts of olivine up to 2 mm. in length. In outward appearance the rock is similar to the nephelite-basalts already described.

Microscopic characters.—The fabric of the rock is seriate intersertal. There are abundant larger crystals of olivine, melilite, and aguite and smaller ones of augite, nephelite, melilite, and magnetite. The rock is holocrystalline, though small areas of weakly polarizing indeterminable materials are present. Plate IV shows photomicrographs of the rock from the Tom Nunn Ranch.

Olivine is abundant with grains ranging from 0.1 mm. in length to 1.25. There is a nearly complete gradation in size between the two extremes of size. A few crystals are euhedral, the greater number being anhedral or subhedral. The crystals are colorless, extensively jointed and cracked and show a slight alteration to serpentine.

Augite, the most abundant mineral of the rock, is present both as large and small crystals, the range in size being from 0.75 mm. to 1.75 mm. The larger crystals are much less abundant than the smaller and there is no gradation in size. The color is grayish-violet with distinct pleochroism discernible in the larger ones. A subhedral lath development characterizes the augite crystals.

Melilite is next to augite in abundance. It is present in colorless euhedral crystals with tabular development parallel to (001). Octagonal basal sections are abundant and rare cruciform twins were noted, both of which are shown in Plate IV. The crystals average .25 mm. in size. The peg structure, characteristic of the mineral, is seen in some of the crystals, though the greater number fail to show this feature. Interference colors of the mineral are of an abnormal blue-gray, and together with cleavage serve to distinguish it from nephelite.

Nephelite is sparingly present as colorless anhedral grains. It is distinguished with difficulty from melilite, but the anhedral development and lack of cleavage serve to separate it.

Magnetite is present as numerous euhedral to anhedral grains. Perovskite is found as a very few minute dark brown to greenish isotropic-grains with very high relief.

A small amount of radiate fibrous material is present. Its low relief and occurrence in amygdaloyd-like relations suggest a zeolitic mineral. This determination, however, has not been made positively.

Serpentine is developed to a slight extent as an alteration product of olivine.

Chemical composition.—No analysis of the nephelite-melilite-basalt from Tom Nunn's Ranch is available. Two analyses of similar rocks from Uvalde County are included as Nos. 3 and 4 of the analyses of nephelite-basalts and related rocks. These analyses show the chemical characters of the rocks, though No. 4 is not as complete as might be wished. There is a question also of the accuracy of determination of some of the constituents in the analysis. Both analyses emphasize the essential features of melilite-bearing rocks, small amounts of silicon and aluminum, abundant iron, calcium, and magnesium. It is to be noted that Analysis 4 shows 6.87 per cent of soda. It is questionable whether soda occurs so abundantly in the rock, since no soda-bearing mineral is present in great amounts. In general the nephelite-melilite-basalts shown here correspond chemically closely to the nephelite-basalts shown. As has been noted previously, the nephelite-basalts are more basic than the average of such rocks.

Classification.—The rocks considered here plainly are properly classed as nephelite-melilite-basalts. They differ from nephelite-basalts in the presence of notable amounts of the mineral melilite.

The two analyses available of the nephelite-melilite-basalts fall into the normative classification of *Uvaldose* and into a subrang without name IV 1.4.2.2. Norms of the nephelite-melilite-basalt are included in the table of norms of the nephelite-basalts.

Variation.—Variations among the nephelite-melilite-basalts are similar to the variations shown in the nephelite-basalts. There is a range in fabric from one in which the ground is in great contrast to the larger crystals to a fabric in which there is a fair degree of gradation between the groundmass and the phenocrysts. The two types of fabric are close to seriate porphyritic and seriate porphyroid.

Mineralogical variations are found among the rocks, but these are not great. Melilite varies from a very minor constituent to an abundant one. The same is true of nephelite. Augite is abundant in all specimens studied. In some specimens segregations of augite (on a microscopic scale) are found. In such rocks the uniformity of the distribution of the minerals is interrupted, due to areas composed entirely of augite. These resemble *schlieren,* found in more acidic rocks.

The mineral melilite, aside from its variation in abundance, shows other variable characters. Basal sections almost invariably exhibit inclusions of brownish-green material which are believed to be the ends of the peg structure. In the tabular sections these inclusions are not apparent, except as lines of the peg structure. In some crystals a beautiful zonal arrangement of the inclusions is common.

In the melilite crystals of some specimens the brownish-green material has completely obscured the melilite, suggesting replacement of the melilite, leaving either a tabular or octagonal patch of amorphous brownish-green material depending upon the section of melilite observed. There are other crystals in which the replacement has been only partial, leaving a central portion of melilite.

A close examination revealed the presence of minute amounts of perosvskite in every specimen. Without examination with high magnification and strong illumination, this mineral is easily mistaken for magnetite.

LIMBURGITIC ROCKS

Among the basaltic rocks of the district a few correspond in a general way to the type of limburgite, though differing in minor detail. Limburgite consists essentially of phenocrysts of olivine and pyroxene in a glassy groundmass. The rocks considered here contain very little glassy material but are free from nephelite or feldspar except for exceedingly small amounts. They are accordingly classed as limburgitic, though they might as correctly perhaps be called fine-grained peridotites. The rocks are classed separately from the other basaltic ones to emphasize the variation which exists and to point out these few examples of the most basic of the rocks in the district.

The localities in which rocks of this sort occur are Pilot Knob, Travis County; South Austin, Travis County; 2½ miles southeast of Asphalt Mountain, Uvalde County; the Batto farm, 2 miles west of Bandera, in Bandera County; 2 miles south of Black Waterhole in Uvalde County; and near Wagontop Hill in southwest Uvalde County. The last locality was mentioned by Cross[19], who called attention to the exceptionally basic character of the rocks found.

Chemical composition.—No superior analyses of the limburgitic rocks are available. One incomplete analysis of the rock at Pilot Knob, Travis County, made many years ago by J. F. Kemp,[20] is given below.

SiO_2	38.35
Al_2O_3	20.32
Fe_2O / FeO	9.18
MgO	13.78
CaO	11.67
Na_2O	2.77
K_2O	2.02
Ign Loss	1.20
	99.29

The low amount of silica is to be noted in this analysis along with high alumina, magnesia and lime. While the analysis is not as complete as might be wished, it serves to show the principal chemical features of the rocks as compared with others of the district. Reference to the complete table of analyses in the section on petrology will show the position of this rock when compared with the others.

Megascopic characters.—Superficially, the limburgitic basalts do not differ from those already described. A slightly greater amount of olivine is noticed in some specimens, but otherwise no difference is noted. The limburgitic rocks are black dense rocks with phenocrysts of olivine and rarely augite.

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[19]Uvalde Folio, U. S. Geol. Surv, p. 5, 1900.

[20]Kemp, J. F., Notes on a nepheline-basalt from Pilot Knob, Texas. Amer. Geol., Vol. 6, pp. 292–294, 1890.

Microscopic characters.—Under the microscope no great difference is observed when these rocks are compared with the basalts previously described. In general felspathic minerals are exceedingly rare and are comprised by nephelite. Augite occurs more abundantly in larger crystals than in the other basalts. The limburgite from Wagontop Hill shows only an occasional grain of nephelite and a little glass. The greater part of the rock is a fine groundmass of augite laths and magnetite grains in which are held numerous larger crystals of olivine and a few larger crystals of augite. A designation as limburgite is thought justifiable because attention is thus called to the mineralogic characters of the rocks. A classification in the C. I. P. W. classification is not made because adequate analyses are not available.

GABBRO

Gabbro defined.—The term gabbro as used here includes phanerocrystalline or coarse-grained igneous rock containing calcic feldspar (labradorite, bytownite or anorthite) with variable amounts of pyroxene, hornblende, biotite, olivine and iron ores. The relative amount of ferromagnesian minerals varies from a virtual absence in anorthosite to preponderance as gabbro approaches peridotite in composition. Since the two occurrences of gabbro known in the area covered by this report are similar, no varietal terms are mentioned.

Occurrence.—Gabbro occurs in Green Mountain north of Uvalde, in Uvalde County, and near Mustang Waterhole north of Cline, in Uvalde County. (Specimens of gabbro reported to be from northern Kinney County, near old Tularosa Post Office, have also been seen, though the locality has not been visited.) In both places the occurrence is north of the main Balcones Fault and on the upthrown side of the fault. This is probably due to the fact that erosion is greatest here, exposing rocks that crystallized under conditions approaching plutonic. In masses not so deeply eroded such conditions are not shown.

Green Mountain is a basaltic stock or plug covering an area of about 3 square miles. The mass is composed of olivine-basalt, but a minor amount of the rock is gabbro. The evidence bearing on the occurrence of the gabbro is somewhat contradictory. The surface of the mountain is covered with a mantle of débris and vegetation so that the exact relation of gabbro to basalt is not revealed. However, judging from occasional outcrops, the gabbro occurs as an elongate or lens-like mass entirely surrounded by basalt. Specimens showing complete gradation from gabbro to basalt were found. In general it seems evident that the gabbro is a textural variation of the basaltic magma and has resulted from the more favorable conditions for crystallization found in the central part of the intrusion. One specimen, however, was found in which gabbro of coarse grain enclosed a block three inches by two inches of fine-grained basalt with sharp boundaries between the two types. This specimen apparently records an intrusive phase of the gabbro. To what extent intrusion of basalt by gabbro has occurred cannot be told. It appears that the gabbro generally is not intrusive into basalt because of the gradation shown between the two types, but simply represents a variation in texture.

The relation of the occurrence to location in regard to the Balcones Fault is significant. The basaltic stock is on the upthrown side and erosion has bared the stock to greater depth here than in the igneous bodies on the downthrown side of the fault. With depth, in the basaltic masses, the texture changes greatly and conditions approach the plutonic rather than hypabyssal. Further discussion of this relationship is found in the section on petrology.

The occurrence of gabbro north of Cline is similar to that of Green Mountain. There is again a stock of basaltic rock with an area of about one and one-half square miles. In the central part of the mass as exposed gabbro is found. As in Green Mountain, gradation is found to basalt and the gabbro is a textural variation of basalt with a minor difference in chemical characters. Furthermore, this occurrence also is low stratigraphically, erosion having reached as far as the Buda limestone.

The two occurrences of gabbro present interesting examples of textural variation among igneous rocks. They comprise cores of the normal basalt occurrence and perhaps are to be expected in all of the basaltic igneous bodies of the region. The variation thus found is due to a difference in physical conditions controlling crystallization. Deeper burial and probably also greater volume of the magma are responsible directly for the types of texture developed. The description of gabbro which follows applies equally well to specimens from Green Mountain and Mustang Waterhole.

Megascopic characters.—Gabbro specimens collected varied in color from light gray to dark gray, depending on the size of crystal and the relative amounts of the different minerals. The texture is phanerocrystalline, equigranular, coarse to medium-grained. The coarsest-grained specimens contain crystals up to 10 mm. in length. Variations downward in size of grain causes the texture to approach that of basalt. The most abundant type seen was medium gray in color with crystals averaging 2.5 mm. The coarsest-grained type with pyroxene crystals up to 10 mm. showed a speckled appearance due to the large dark-colored pyroxene crystals contrasted with the light of the feldspars.

Microscopic characters.—Under the microscope the rock is seen to be holocrystalline, equigranular and fairly coarse-grained. The predominant mineral is plagioclase feldspar, which comprises more than 50 per cent of the rock. Augite, olivine and magnetite are other prominent constituents. The fabric approaches the ophitic, though feldspar and augite overlap in their periods of crystallization. Figure 1, Plate V, shows the rock from Green Mountain.

The feldspar is labradorite. It is present in prominent lath-shaped crystals with albite twinning. Inclusions of apatite, biotite and iron ores are common.

Augite occurs as large violet-colored crystals, a few of which are euhedral. Inclusions of magnetite, biotite and apatite are present.

Olivine is not abundant but is found in a few anhedral colorless grains partly altered to serpentine.

The accessory minerals include magnetite, apatite, biotite and titanite. These are present in minor amounts. Magnetite frequently is surrounded by a rim of biotite, as in the case of olivine-basalts previously mentioned. Biotite also occurs as scattered pleochroic flakes. Apatite is common and shows many prismatic crystals with euhedral outlines. Only a very few small lozenge-shaped titanite crystals were noted.

Chemical composition.—Chemical analyses of the gabbro and basalt from Green Mountain are given below, along with rocks related to the gabbro. In the normative classification the rocks from Green Mountain fall into different classes, the gabbro being *limburgose,* the basalt *camptonose.*

Analyses of Gabbro and Related Rocks

	1	2	3	4	5	6	7
SiO_2	47.51	45.30	44.82	43.65	43.92	43.04	43.72
Al_2O_3	15.52	12.66	13.68	11.48	15.87	14.76	17.32
Fe_2O_3	3.25	2.93	2.76	6.32	8.45	4.91	7.21
FeO	5.96	10.54	7.57	8.00	5.59	8.52	6.03
MgO	5.85	8.39	10.11	7.92	5.20	8.27	6.01
CaO	14.05	11.86	12.76	14.00	12.86	13.03	12.00
Na_2O	3.21	2.65	2.83	2.28	4.08	2.70	3.40
K_2O	1.32	0.66	0.80	1.51	1.41	1.44	1.57
H_2O+ H_2O-	1.89	1.79	2.81	1.00	2.03	0.80	1.80
TiO_2	0.51	1.68	1.35	4.00	0.71	2.50	0.81
P_2O_5	0.89	0.89	0.15	trace	......	0.35	0.32
	99.96	99.35	99.73	100.16	100.12	100.32	100.19

1. Gabbro, from Green Mountain, Uvalde County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.

2. Olivine-basalt, from Green Mountain, Uvalde County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.

3. Limburgite, Los Amolanos, Atacama, Chile.
4. Olivine-gabbro-diabase, Brandberget, Gran, Norway.
5. Nephlite-basanite, Armannsberg, near Kemnath, Bavaria.
6. Monchiquite, Topsail Point, Tamora Island, Los Islands, French Guinea.
7. Trachydolerite, Sadder Hill, St. Helena Island.

The principal differences between the gabbro and basalt consist in the distribution of iron, magnesia, lime and soda. This is shown also in the minerals of the rocks, since there is a relatively large proportion of plagioclase in the gabbro and of augite in the basalt. These chemical differences are probably due to differentiation whereby the iron and magnesia were more highly concentrated in the outer cooler part of the magma, while lime and soda were concentrated in the central part. The basalt can, perhaps, be considered as a basic border zone.

Classification.—From a mineralogic standpoint the gabbro is plainly within the definition of gabbro, since it contains large amounts of calcic plagioclase along with augite. The norms given below permit the classification of *limburgose* in the qauntitative system. The norms and classification of the other rocks are also given.

Norms of Gabbro and Related Rocks

or	7.78	3.89	5.00	8.90	8.34	8.34	9.45
ab	12.05	18.34	8.12	5.50	7.86	3.67	8.91
an	23.91	21.13	23.35	16.96	20.57	23.91	27.24
ne	8.24	1.99	8.38	7.52	14.48	10.51	10.79
di	35.25	26.77	31.23	41.33	32.04	30.98	24.08
ol	3.70	16.10	14.36	2.27	1.16	9.51	5.18
mt	5.10	4.18	3.94	9.05	12.30	7.19	10.44
il	0.91	3.04	2.58	7.60	1.37	4.71	1.52
ap	2.02	2.02	------	------	------	0.67	0.67

$$\text{Class: } \frac{\text{Sal}}{\text{Fem}} = \frac{51.98}{44.98} = 1.1 = \text{III, salfemane}$$

$$\text{Order: } \frac{\text{L}}{\text{F}} = \frac{8.24}{43.74} = .18 = 6, \text{ portugare}$$

Rang: $\frac{K_2O' + Na_2O'}{CaO'} = \frac{66}{86} = .75 = 3$, limburgase

Subrang: $\frac{K_2O'}{NO_2O'} = \frac{14}{12} = .26 = 4$, limburgose

2. III.5.3.4.
3. III"6.3(4).4"
4. III(IV).6.3.4.
5. III.6.3.4.
6. III,6.3".4.
7. III,6.3".4.

PHONOLITIC ROCKS

Phonolitic rocks in the area covered by this report are restricted to the Uvalde district where a number of occurrences are found. The rocks vary considerably mineralogically, chemically, and texturally, and do not correspond exactly to type definitions. They present a very interesting example of variation, and are here grouped together under the general heading of phonolitic rocks, though varietal names can be assigned certain specimens.

A strict adherence to nomenclature would distinguish among the phonolitic rocks, phonolite, nephelinite and a rock intermediate between basanite and phonolite, called here Uvalde phonolite. Furthermore, gradational varieties between these species occur. For clearness, species mentioned are defined.

Phonolite: An aphanitic rock with or without phenocrysts consisting of alkali-feldspar and feldspathoid with pyroxenes and amphiboles. There is a wide variation in the amounts of the constituents.

Nephelinite: An aphanitic or porphyritic rock composed essentially of augite and nephelite without olivine or feldspar.

Basanite: A basaltic rock generally porphyritic containing plagioclase, augite, olivine, and a feldspathoid. The Uvalde phonolite is a graditional rock less basic than true basanite, but related to it.

PHONOLITE

As an example of phonolite, the rock found at Ange Siding, 4 miles northeast of Uvalde, may be cited. The rock corresponds rather closely to the definition.

Megascopic characters.—The phonolite is exceedingly fine-grained and is greenish-gray in color. Phenocrysts of feldspar and nephelite are fairly abundant and reach dimensions of 4 mm. The rock weathers light grayish in contrast to the basalts of the region.

Microscopic characters.—The fabric of this rock is seriate porphyritic. The groundmass is exceedingly fine and in it are phenocrysts of sanadine, nephelite, and hornblende resorbed to form pyroxene and magnetite. Figure 2, Plate V, shows a thin section of the rock.

Nephelite occurs as phenocrysts with euhedral development. They are not abundant but are noticeable both in the hand specimens and under the microscope. The groundmass, as far as it can be resolved, also contains nephelite in small prismatic crystals.

Sanadine is present as phenocrysts of the same rank as nephelite, from which is distinguished by the cleavage and its biaxial character. This mineral is present as phenocrysts to a slight extent and is also present in the groundmass along with nephelite.

Aegirite-augite is abundantly present in the groundmass along with nephelite and sanadine. It occurs as minute needles with a bright green color.

Remnants of hornblende crystals are present in the rock to a slight extent. These show an alteration to pyroxene and magnetite through resorption. All stages of the process are shown from partial alteration to complete recrystallization of the paramorph minerals.

The phonolite at Ange Siding conforms colsely to the type definition. Nephelite, sanadine and aegirite-augite are the important minerals. The groundmass is very fine, but is felsitic in composition. In it, grains favorable for identification have been identified as nephelite and alkali-feldspar. Presumably the rest of the groundmass is similar in composition. The rock from its mineral characters is decidedly alkaline in character, and can safely be placed as a phonolite.

NEPHELINITE

Rocks corresponding to nephelinite have been found 2 miles south of Black Waterhole in Uvalde County, where there are two prominent plugs of igneous rock situated about one-half mile apart. Both plugs are phonolitic, the southernmost one corresponding to nephelinite, the other being transitional toward phonolite. Between the two occurrences with no physiographic relief is an occurrence of basalt.

Megascopic characters.—The rock called nephelinite is quite similar to phonolite in the hand specimen. There is the same very fine texture. The color is slightly darker, lacking the greenish tint of the phonolite, and phenocrysts apparent to the unaided eye are rare or lacking. Weathered surfaces are gray in color.

Microscopic characters.—The nephelinite is essentially a two-mineral rock, more than 90 per cent being composed of the two minerals, nephelite and aegirite-augite. Of the two, nephelite is the most abundant, though aegirite-augite is not scarce. Estimated proportions for the two are 55 and 35. An occasional crystal of altered (resorbed) hornblende and an exceedingly small amount of magnetite are noted. There is no groundmass, though a small amount of dense interstitial material occurs.

The fabric of the rock is very striking. Although so fine-grained as to appear aphanitic in the hand specimen, the microscope shows a remarkable development of euhedral nephelite crystals surrounded by, and separated by, minute needles of aegirite-augite. A very few crystals of nephelite are large enough to constitute phenocrysts, as is the case also with a few of the aegirite-augite crystals, but except for these, the rock presents a nearly equigranular fabric in great contrast to other rocks of the region whether basaltic or phonolitic. Strictly speaking, the texture would be classed either as seriate homeoid or just within the limits of the term equigranular. Figure 1, Plate VI, illustrates the texture of the rock.

The mineralogy of the nephelinite as indicated above is fairly simple. Nephelite is the most abundant species, being present as colorless prismatic or basal section nearly all of which show euhedral outlines. These vary in size from a few large crystals .3 mm. in greatest dimension, down to minute crystals less than .02 mm., the average and most abundant being about .08 mm. The striking character of the crystals is their uniformly euhedral development. Nephelite was the first mineral of the magma to crystallize and hence was free from to form nearly perfect crystals.

Aegirite-augite is abundant as small needles lying between nephelite crystals. Its size is comparable to that of the smaller nephelites. A few crystals, as in the case of nephelite, attain greater dimensions, the maximum observed being .6 mm. The mineral is vivid green in color and faintly pleochroic. Occasional zoned crystals show central portions less sodic than the majority of the crystals. In these there is a marked difference between the optical properties of the two zones. The less sodic variety corresponding to normal augite is grayish in color.

A very few paramorphic crystals of brown pleochroic hornblende occur in the rock. These have been partially resorbed with the formation of aegirite-augite and to a lesser extent magnetite.

Appreciable amounts of other constituents are lacking in the rock. It is one with a simple mineralogic composition but a striking textural development. Superficially (in the hand specimen) the rock resembles others found in the district, but it differs in the abundance of nephelite, lack of feldspar, and virtual lack of femic minerals except aegirite-augite.

UVALDE PHONOLITE

The rock at Mt. Inge, 3 miles southwest of Uvalde, is intermediate in character between phonolite and basanite. It was described by Osann[21] as nephelite-basanite but later

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[21]Osann, A., Melilite-nepheline-basalt and nepheline-basanite from Southern Texas. Jour. Geol., Vol. 1, pp. 341–346, 1893.

Cross[22] showed that the rock does not contain soda-lime feldspar and is more closely related to phonolite than basanite. He designated the rock Uvalde phonolite and this name is retained here. Before the rock was studied by Cross samples were labelled basanite following Osann, and this name unfortunately appears in the list of analyses from the laboratory of the United States Geological Survey. The later designation of Uvalde phonolite made by Cross in the Uvalde Folio is correct.

It must be recognized that the rock under discussion does have basanitic affinities. It apparently varies mineralogically from place to place to a certain extent. Sections examined by the writer do not contain determinable plagioclase feldspar but are lower in alkalies and richer in lime and the mafic minerals, such as olivine and augite, than normal phonolites. The minerals present and the analyses quoted later show that this rock is transitional between phonolite and basanite. Probably the rock is the most basic of the phonolitic ones found here, since it contains olivine, and basaltic-augite showing its relation to more basic facies.

Rock very similar to that of Mt. Inge is found near Big Mountain, also in Uvalde County. An analysis made in the laboratories of the United States Geological Survey shows the resemblance of the rocks. The rock from near Big Mountain, for the reasons mentioned above, will be grouped with that of Mt. Inge.

Megascopic characters.—A fresh surface of the rock shows a medium to dark gray color. The greenish tint of the phonolites is entirely lacking. The texture is porphyritic with a very fine-grained groundmass, in which are imbedded recognizable crystals of nephelite, feldspar and hornblende. Feldspars attain a maximum length of 5 mm., nephelite 3 mm., hornblende 5 mm. An occasional phenocryst of olivine is noted. The rock weathers to a light gray.

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[22]Cross, W., U. S. Geol. Surv., Geologic Atlas, Uvalde Folio No. 64, p. 4, 1890.

Microscopic characters.—The texture of the rock is seriate porphyritic. The appearance of the rock in thin section is very striking because of the number and variety of phenocrysts. This is shown in Figure 2, Plate VI. The groundmass is grayish to greenish, and in it are innumerable phenocrysts of hornblende, augite, magnetite, olivine, feldspar, aegirite-augite, and nephelite. The groundmass is exceedingly fine, being resolved only with great difficulty. It is felsitic with nephelite, aegirite-augite and feldspar.

Pyroxene present in the rock includes both aegirite-augite and augite. Stout prismatic crystals of augite with euhedral development are contrasted with prismatic needles of aegirite-augite. The color varies from green to violet. The pyroxenes occur both in the groundmass and as phenocrysts.

Hornblende is present only as residuals from the resorption process. Many of these show euhedral outlines of hornblende, but only the central part of the paramorph remains as hornblende. The outer portions are recrystallized to an aggregate of small grains and crystals of pyroxene and magnetite. Many such crystals occur in which the alteration has been complete and in which an aggregate of the two minerals is left with the crystal outlines of hornblende.

Feldspar of the variety sanadine occurs in phenocrysts throughout the rock. It is far less abundant than augite or hornblende. The same is true of nephelite, which also is present as scattered phonocrysts. An occasional crystal of olivine is noted.

The minerals of the groundmass present great difficulty in determination. Minute crystals of augite and aegirite-augite are readily discernible as are minute grains of magnetite. The rest of the groundmass, and by far its greater part, is a very fine felsitic aggregate in which laths of orthoclase and nephelite are recognized.

The contrast between this rock and the two phonolitic ones already described is great. There is a greater amount of mafic minerals hornblende, augite, and magnetite. In the phonolite and nephelinite these minerals, except green aegirite-augite were comparatively rare while here they are abundant. It is to be noted further that olivine is found in some abundance. Nephelite is not prominent as in the case of the previous rocks, while feldspar is of greater importance.

Chemical composition and classification.—In the following table available chemical analyses of the phonolitic rocks are given. This is followed by tables showing the norms calculated for the rocks and the normative classification which can be assigned to them. The average phonolite and basanite of Daly are also listed.

Analyses of Phonolitic Rocks

	1	2	3	4	5	6	7	8
SiO_2	54.42	48.23	48.13	51.97	51.25	52.51	57.45	44.41
Al_2O_3	20.76	17.43	18.44	18.79	18.07	18.21	20.60	15.81
Fe_2O_3	2.64	2.77	3.41	2.77	3.16	2.46	2.35	4.66
FeO	1.33	5.92	4.30	3.05	3.67	3.33	1.03	5.85
MgO	0.22	2.99	3.06	0.51	0.65	0.60	0.30	8.20
CaO	1.34	6.38	5.89	2.84	3.70	2.75	1.50	10.12
Na_2O	10.41	6.87	8.00	8.70	8.98	8.84	8.84	3.81
K_2O	4.89	2.78	3.80	5.50	4.70	5.78	5.23	2.37
H_2O+	2.50	2.84	1.59	4.00	4.56	3.70	2.04	2.42
H_2O-	0.22	0.54	0.18	0.65	0.45	0.40		
TiO_2	0.40	2.00	1.74	0.80	0.80	0.80	0.41	1.56
P_2O_5	0.11	0.69	0.49	0.22	0.24	0.13	0.12	0.65
MnO	0.15	0.18	0.19	......	......	......	0.13	0.14
Incl	0.43	0.32	0.71	......	......	......	......	......
	99.82	99.97	99.93	99.80	100.23	99.51	100.00	100.00

1. Phonolite, between Black and Big mountains, Uvalde County, Texas. W. Cross, U. S. Geol. Surv. Bull. 168, p. 62, 1900.
2. Phonolite allied to No. 3, near Big Mountain, Uvalde County, Texas. W. F. Hillebrand, analyst. U. S. Geol. Surv. Bull. 168, p. 61, 1900.
3. Uvalde phonolite, Mount Inge, Uvalde County, Texas. W. F. Hillebrand, analyst. U. S. Geol. Surv. Bull. 1662, p. 61, 1900.
4. Phonolite, Ange Siding, Uvalde County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.
5. Phonolite, Conners Ranch, Uvalde County, Texas. J. E. Stullken, analyst.

6. Nephelinite, 2 miles south of Black Waterhole, Uvalde County, Texas. J. E. Stullken, analyst.
7. Average phonolite, Daly, R. A., Igneous Rocks and Their Origin, p. 24, 1914.
8. Average basanite, Daly, R. A., *ibid.*, p. 31.

Norms of Phonolitic Rocks

	1	2	3	4	5	6	7	8
or	29.47	16.68	22.24	32.80	27.80	34.47	30.58	15.57
ab	23.32	23.84	14.67	14.67	11.00	13.10	42.44	11.00
ne	29.96	18.60	27.55	27.55	29.82	25.84	17.32	12.50
ac	7.39	------	------	6.93	9.24	7.39	------	------
ns	0.24	------	------	------	1.83	1.22	------	------
di	5.02	15.13	17.86	9.79	13.62	11.00	0.75	21.40
wo	0.35	------	------	0.70	0.70	------	0.46	------
il	0.76	3.80	3.34	1.52	1.52	1.52	0.76	8.21
mt	------	3.94	4.87	0.70	------	------	2.09	4.18
an	------	8.34	4.17	------	------	------	1.39	8.06
ol	------	4.18	1.56	------	------	0.44	------	16.42
ap	------	1.68	1.01	0.34	0.34	0.34	0.34	1.68
hl	------	------	0.47	------	------	------	------	------
hm	------	------	------	------	------	------	0.96	------
	------	------	------	------	------	------	------	------

(1)

Class: $\frac{\text{Sal}}{\text{Fem}} = \frac{82.75}{13.76} = 6 = \text{II}$, dosalane

Order: $\frac{\text{L}}{\text{F}} = \frac{29.96}{52.79} = .56 = 6$, norgare

Rang: $\frac{K_2O' + Na_2O'}{CaO'} = \frac{197}{0} = \infty = 1$, laurdalase

Subrang: $\frac{K_2O'}{Na_2O'} = \frac{53}{149} = .35 = 4$, laurdalose

(2)

Class: $\frac{\text{Sal}}{\text{Fem}} = \frac{77.46}{28.73} = 2.3 = \text{II}$, dosalane

Order: $\frac{L}{F} = \frac{18.60}{48.86} = .38 = 6$, norgare

Rang: $\frac{K_2O' + Na_2O'}{CaO'} = \frac{140}{30} = 4.6 = 2$, essexase

Subrang: $\frac{K_2O'}{Na_2O'} = \frac{30}{110} = .27 = 4$, essexose

(3)

Class: $\frac{Sal}{Fem} = \frac{69.10}{28.64} = 2.4 = II$, dosalane

Order: $\frac{L}{F} = \frac{27.55}{41.08} = .67 = 7$, italare

Rang: $\frac{K_2O' + Na_2O'}{CaO'} = \frac{228}{23} = 9.9 = 1$, lujavrase

Subrang: $\frac{K_2O'}{Na_2O'} = \frac{40}{188} = .21 = 4$, lujavrose

(4)

Class: $\frac{Sal}{Fem} = \frac{75.02}{19.98} = 3.7 = II$, dosalane

Order: $\frac{L}{F} = \frac{27.55}{47.44} = .58 = 6$, norgare

Rang: $\frac{K_2O' + Na_2O'}{CaO'} = \frac{184}{0} = \infty = 1$, laurdalase

Subrang: $\frac{K_2O'}{Na_2O'} = \frac{59}{125} = .47 = 4$, laurdalose

(5)

Class: $\frac{Sal}{Fem} = \frac{68.62}{27.25} = 2.5 = II$, dosalane

Order: $\frac{L}{F} = \frac{29.82}{38.80} = .76 = 7$, italare

Rang: $\frac{K_2O'+Na_2O'}{CaO'} = \frac{176}{0} = \infty = 1$, lujavrase

Subrang: $\frac{K_2O'}{Na_2O'} = \frac{50}{126} = .39 = 4$, lujavrose

(6)

Class: $\frac{Sal}{Fem} = \frac{73.41}{22.19} = 3.3 = II$, dosalane

Order: $\frac{L}{F} = \frac{25.84}{47.57} = .54 = 6$, norgare

Rang: $\frac{K_2O'+Na_2O'}{CaO'} = \frac{178}{0} = \infty = 1$, laurdalase

Subrang: $\frac{K_2O'}{Na_2O'} = \frac{62}{116} = .53 = 4$, laurdalose

Discussion of Analyses.—In the preceding table the available analyses of phonolitic rocks from the district are recorded. Three of the analyses of the rocks from Mt. Inge, from a locality between Black and Big mountains and from near Big Mountain in Uvalde County, are taken from United States Geological Survey publications already cited. Three others of rocks from Ange Siding, Conners' Ranch and a locality 2 miles south of Black Waterhole, were made for the present work. While it would be desirable to have additional analyses, the six available are sufficient to show the main characters of the rocks. The first six analyses are of Uvalde rocks, while the last two are averages of phonolites and basanites compiled by R. A. Daly and listed here for purposes of comparison.

The phonolite in column 1 corresponds fairly well to the average phonolite, and can be taken as representative. The essential characters of the rock are: silica, rather low

(54.42%), alumina high, soda and potash high, lime and magnesia low. It is to be especially noted that the last two, lime and magnesia, are present in very small amounts only. Both combined are less than 1 per cent. Soda and potash, on the other hand, are more than 15 per cent of the rock. The rock is decidedly alkaline as contrasted with basalts of the region. Furthermore, the rock is predominantly sodic, since soda is more than twice potash in amount. Comparison with the analysis of column 8, the average phonolite shows a fairly close correspondence.

Numbers 2 and 3 are analyses of the Uvalde phonolite and of a related rock from near Big Mountain. The two analyses are essentially the same and show a marked contrast with the one previously discussed. Silica is less than 50 per cent, alumina is lower, magnesia and lime are nearly as much as potash and soda. The rocks, instead of being strikingly alkaline, are more nearly calcialkalic in character. Soda predominates over potash as before. In the examination of these rocks plagioclase feldspar was not identified. The analyses, however, suggest that it may be present molecularly at least since the norms calculated by Washington for the rocks show normative anorthite in both cases. When compared with the average basanite in column 9 it is seen that the rocks show considerable differences. The average basanite is lower in silica and alumina, much higher in iron, and decidedly higher in both lime and magnesia, while soda and potash are lower. The rock shown by the average analysis would be nearer the calcic extreme than any of the rocks found in the Uvalde district for which analyses are available. The comparison emphasizes the fact that the Uvalde phonolite and similar rocks form transitions between basanite and the more alkaline phonolites.

The remaining three analyses of the phonolites from Ange Siding and Conner's Ranch and of the nephelinite are generally intermediate between the extremes already discussed. These analyses exhibit characters which might be predicted from the microscopic study of the rocks. The phonolite at

Conner's ranch corresponds more closely to the Uvalde phonolite than to the more alkaline phonolites, although it occupies an intermediate position. This rock contains abundant hornblende and some olivine in addition to the usual minerals of the phonolites. The nephelinite is also intermediate in position, but does not differ widely from the phonolite in column 1. Altogether it is felt that these analyses of the phonolitic rocks of the district serve to emphasize the significant character which is the considerable variation both chemical and mineralogical existing among these small and closely spaced bodies of rock. In this connection it is noted that the nephelenite described outcrops only one-half mile from another phonolitic mass from which it differs quite widely; furthermore, that the phonolite, the analysis of which appears above, occurs only a short distance from the phonolite near Big Mountain and as is readily seen these rocks differ to a considerable extent.

In the tables above the norms and normative classification of the rocks are also given. The norms bring out again the similarity between the two representatives of the Uvalde type and their contrast with the phonolites. In the one case normative anorthite and abundant diopside are listed. In the phonolites the anorthite is absent, diopside is much less and a notable amount of acmite is present. Furthermore, the phonolites lack the olivine, and magnetite abundantly developed in the norms of the basanites. The table of norms also emphasizes the intermediate position of the rocks in columns 4, 5, and 6. The rock from Conner's Ranch has no anorthite but does have a relatively large amount of diopside showing its basanite affinities. Comparisons of all three of these norms with regard to the various normative minerals shows their intermediate position.

Reference to the table following the tables of norms show the normative classification of the rocks, three being from Washington's list. Three subrangs are represented *laurdalose, essexose and lujavrose.* The treatment of these rocks is different than of the basalts where rocks falling in different normative classes were separated. Here all of the phonolitic rocks are included together because their variation is marked and the method emphasizes the variation. Every method of examination of these rocks serves to bring out the variation present. Exposures number only eight, but there are three varieties of rocks shown from the limited data available. It is possible that additional anlyses would reveal still greater variation.

PEGMATITE

In the rocks at Mt. Inge and at the phonolite mass north of Uvalde three are veinlets and threads of a rock which is here classed as pegmatite. These are exceedingly rare, never more than an inch wide and are found with difficulty. Their occurrence is similar to that of normal pegmatite and they are thought to have originated in a similar manner.

Because of the lack of specimens very few details of this material are known. The texture is coarse with crystals up to 1 cm. long. Mineralogically the rock consists almost entirely of potash feldspar orthoclase or sanadine, and a small amount of aegirite-augite in fairly large crystals.

The occurrence of this rock seems to be explained on the basis of the occurrence of pegmatite. It represents apparently a very minor part of the magma more mobile than the rest which crystallized after the main mass had frozen. At no other places in the district have rocks analogous to this material been found.

PETROLOGY OF THE IGNEOUS ROCKS

As has been stated in a previous section of this report, the igneous rocks of the Balcones Fault region are found in a narrow belt coincident with and probably determined by faulting. The localization of the igneous rocks to a belt in which general conditions are similar leads to the belief that the various igneous rocks are related in origin, and that they should exhibit characters revealing relationship or consanguinity between them. The present section of the report discusses this matter, and since the rocks form a distinct unit from many standpoints they furnish an unusually fine subject for petrologic study and discussion. Although the analyses available for this discussion are few in number and although they limit the extent of the study, enough data are available to show that a relationship exists among the rock and to afford a basis for some theories as to the causes of variations seen in the different localities.

REVIEW OF PETROGRAPHIC CHARACTERS

Mineral composition.—Four general groups of minerals are the most important in the greater number of the rocks under consideration. The most important assemblage is plagioclase, olivine and augite, next is nephelite, augite and olivine, next, nephelite, melilite, augite and olivine, while last in importance is aegirite-augite, nephelite, and sanadine. These vary greatly in amount in the various rocks as has already been indicated. Hornblende and biotite are rarely present, the former being found in the phonolitic rocks as a residual material where resorption has been incomplete, while biotite is found in one or two of the plagioclase-bearing rocks. Magnetite is present in practically all of the rocks but is of least importance in the phonolitic ones. Probably this mineral is not accompanied by ilmenite, since most of the augite is distinctly violet colored. These are the most important and most abundant minerals. The minor accessory minerals are not considered here because they have no great bearing on the present discussion.

The plagioclase present in the basalts in most cases is a difficult subject of study because of the very fine texture of the rocks. In the gabbros and a few of the basalts, however, it is possible to isolate the mineral and secure data of value in the present discussion. From the normative standpoint all of the plagioclase represented by analyses of the rocks can be classified. A list showing the plagioclase present follows:

Albite in Nos. 1, 2, 3, 4.
Oligoclase in No. 7.
Andesine in No. 6.
Labradorite in Nos. 8, 9, 10.
Anorthite in Nos. 11, 12, 15.

Of the rocks the analyses of which are listed on page 95 only three, 8, 9, and 10, contain modal plagioclase in noticeable amounts. These are the olivine-basalts and gabbros. From calculations their plagioclase is sodic labradorite with an average composition of Ab 1, An. 1.5. Actually the modal plagioclase is also of this variety as determinations of the indices of refraction show. For the three rocks represented by the analyses the agreement between normative and modal plagioclase must be very close indeed.

In the other rocks in the norms of which plagioclase appears a different conditions is found. In Nos. 11, 12, and 15 no plagioclase occurs in the mode. Since these rocks are crystalline and can be examined in detail this statement is made with confidence. In Nos. 1, 2, 3, 4, 6, and 7 the rocks are phonolitic and possess dense groundmasses which defy resolution. In these rocks any plagioclase present is in this dense groundmass and while the amount cannot be told, it is believed that plagioclase is less than the norm shows and that the norm and mode of these rocks are far apart. In the phonolites which these analyses represent a large part of the soda in the normative albite is present in modal aegirite-augite.

Orthoclase, in the phonolitic rocks, is more prominent from the normative standpoint than plagioclase. It is believed that the norm is in close agreement with the mode, though no check can be made of this statement. Hornblende present in the phonolites no doubt includes some potash, but since the hornblende is relatively scanty, the amount of potash so combined must be small. The groundmass of the phonolites is largely alkali-feldspar which may be soda-bearing, but which certainly accounts for most of the potash in the norm. In the basaltic rocks, either plagioclase-bearing or nephelite-bearing, orthoclase is a very minor constituent in the norms. It is noticed occasionally in sections of these rocks and probably the norm and mode are not far apart.

Of the lenad minerals only nephelite is of importance in the greater number of the rocks though leucite appears up to nearly 5 per cent in the norms of three. Nephelite is present in the norm of every rock for which an adequate analysis is available. It is present in the mode of all of the rocks except Nos, 8, 9, and 10. In the phonolites a considerable part of the soda of the normative nephelite no doubt is combined in modal aegirite-augite, but in the rest of the rocks modal nephelite corresponds closely to normative nephelite since there are no minerals present except augite with which soda could be included. The augite as shown later probably contains in the aggregate only a relatively small amount of soda.

The pyroxene of the rocks consists of augite and aegirite-augite with perhaps gradational varieties between the two. The augite proper is the titanium rich, violet-colored type, apparently of fairly uniform composition. A few zoned crystals occur, suggesting variation in the composition of the mineral but these are not abundant. This type of augite is found only in the basalts. An analysis of augite from one of the nephelite-basalts has been given earlier in the report.

It will be noted that the mineral contains but slight amounts of either potash or soda. On the other hand, alumina is rather prominent.

The aegirite-augite is found only in the phonolites along with augite differing from that of the basalts. The typical aegirite-augite is grass-green and occurs in slender prismatic crystals. Associated with it are prismatic crystals of light green to colorless augite and into which it seems to grade. The colorless augite of these rocks is probably poor in titanium, as would be expected from the analyses. The soda of the augite and aegirite-augite varies in amount presumably directly with the color of the minerals. It appears in the norm as albite or nephelite.

Olivine appears in the mode of all of the rocks except the most alkaline of the phonolites, that is, in Nos. 4 to 15, inclusive. It appears in the norm of Nos. 6 to 15, appearing as a maximum in No. 12, a nephelite-basalt. The mineral is abundant in all of the basalts and probably corresponds fairly closely in amount to the amounts given in the norms. The mineral, judging from its alteration, is relatively poor in iron as compared with magnesium.

Chemical composition.—In the following table all of the available anaylses of the Balcones Fault rocks are given. Fourteen of these are thought to be of good quality, while the rest are incomplete or of doubtful accuracy, though reference to them will be made. While the table should contain many more analyses for a complete study of the chemical nature of the rocks considered here, these analyses can be considered as typical of classes into which the rocks can be divided.

Analyses of the Igneous Rocks

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
SiO_2	54.42	52.51	51.97	51.25	50.00	48.23	48.13	47.51	45.30	45.11	40.32	39.92	38.35	38.00	37.96	37.42	35.76
Al_2O_3	20.76	18.21	18.79	18.07	16.93	17.43	18.44	15.52	12.66	12.44	9.46	8.60	20.32	26.76	10.14	7.96	18.65
Fe_2O_3	2.64	2.46	2.77	3.16	1.01	2.77	3.41	3.25	2.93	2.67	4.75	4.40	9.18	14.36	3.69	4.86	10.27
FeO	1.33	3.33	3.05	3.67	10.40	5.92	4.30	5.96	10.54	9.36	7.48	8.00			7.59	6.42	
MgO	0.22	0.60	0.51	0.65	1.50	2.99	3.06	5.85	8.39	11.56	18.12	20.17	13.78	—	14.69	16.00	11.26
CaO	1.34	2.75	2.84	3.70	12.94	6.38	5.89	14.05	11.86	10.61	10.55	10.68	11.67	14.89	16.28	13.87	12.52
Na_2O	10.41	8.84	8.70	8.98	2.96	6.87	8.00	3.21	2.66	3.05	2.62	1.91	2.77	2.32	2.18	6.87	5.42
K_2O	4.89	5.78	5.50	4.70	0.88	2.78	3.80	1.32	0.66	1.01	1.10	1.03	2.02	0.64	0.69	trace	1.13
H_2O+	2.50	3.70	4.00	4.56	1.23	2.84	1.59	1.89	1.79	0.78	1.25	1.45	—	—	1.82	2.65	—
H_2O-	0.22	0.40	0.65	0.45	0.25	0.54	0.18			1.06	0.57	0.43	—	—	0.39	0.39	—
TiO_2	0.40	0.80	0.80	0.80	1.50	2.00	1.74	0.51	1.68	2.34	2.66	2.70	—	—	2.93	3.20	—
P_2O_5	0.11	0.13	0.22	0.24	trace	0.69	0.49	0.89	0.89	0.51	0.68	0.51	—	—	1.13	trace	—
MnO	0.15	—	—	—	—	0.18	0.19	—	—	0.22	0.25	0.24	—	—	0.22	—	—
CO_2	—	—	—	—	—	—	—	—	—	—	—	—	—	0.82	—	—	0.10
Ign Loss	—	—	—	—	—	—	—	—	—	—	—	—	1.20	1.76	—	—	2.65
Incl	0.43	—	—	—	—	0.32	0.71	—	—	0.20	0.28	0.41	—	0.82	0.42	—	1.85
Total	99.82	99.51	99.80	100.23	99.60	99.97	99.93	99.96	99.35	100.02	100.09	100.45	99.29	99.55	100.13	99.64	99.61

1. Phonolite, between Black and Big Mountains, Uvalde County, Texas. Cross, W., U. S. Geol. Surv. Bull. 168, p. 62, 1900.
2. Nephelinite, 2 miles south of Black Waterhole, Uvalde County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.
3. Phonolite, Ange Siding, Uvalde County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.
4. Phonolite, Conner's Ranch, Uvalde County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.
5. Olivine-basalt, Mustang Waterhole, north of Cline, Uvalde County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.
6. Basanite, near Big Mountain, Uvalde County, Texas. Vaughan, T. W., U. S. Geol. Surv. Bull. 168, p. 61, 1900.
7. Basanite, Mount Inge, Uvalde County, Texas. Cross, W., U. S. Geol. Surv. Bull. 168, p. 61, 1900.
8. Gabbro, Green Mountain, Uvalde County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.
9. Olivine-basalt, Green Mountain, Uvalde County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.
10. Basalt, Pinto Mountain, Kinney County, Texas. Cross, W., U. S. Geol. Surv. Bull. 168, p. 61, 1900.
11. Nephelite-basalt, Tom Nunn's Hill, Uvalde County, Texas. Cross, W., U. S. Geol. Surv. Bull. 168, p. 62, 1900.
12. Nephelite-basalt, Black Mountain, Uvalde County, Texas. Cross, W., U. S. Geol. Surv. Bull. 168, p. 63, 1900.
13. Basalt, Pilot Knob, Travis County, Texas. Kemp, J. F., Amer. Geol., Vol. VI, p. 293, 1890.
14. Basalt, Pilot Knob, Travis County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.
15. Nephelite-melilite-basalt, near Uvalde, Uvalde County, Texas. Cross, W., U. S. Geol. Surv. Bull. 168, p. 63, 1900.
16. Nephelite-melilite-basalt, Black Waterhole, Uvalde County, Texas. J. E. Stullken, chemist, Industrial Chemistry Experiment Station, University of Texas, analyst.
17. Nephelite-basalt, Quarry of Texas Trap Rock Company, Knippa, Uvalde County, Texas. J. E. Stullken, Industrial Chemistry Experiment Station, University of Texas, analyst.

Silica in the seventeen analyses ranges from a maximum of about 55 per cent to a minimum of about 26, and it is to be noted that the range in this oxide is rather uniform. All of the analyses showing less than 40 per cent of silica are to be considered as notably basic, while the one with greatest amount of silica is not an acidic rock.

Alumina ranges from 20.76 per cent to 8.60 in the better analyses. No. 14 records 26.76 per cent of the material, but the figure must be accepted with reservations since the analysis is not complete. This rather marked range in alumina is shown in the normative minerals containing this oxide by the considerable variation in amounts in comparison with the silica.

The iron oxides ferric and ferrous are shown in the tables with a rather constant relationship. It is worthy of note that the total iron content of the rocks is rather uniform throughout, though the phonolites contain less than the basalts.

It is in the case of magnesia that the greatest variation of amount is seen. The range is from less than 1 per cent to more than 20. Lime likewise varies between wide limits, the extremes being a little more than 1 per cent and more than 16 per cent.

The alkali oxides, soda and potash, vary between wide limits but are proportionally more constant than either lime or magnesia. The smallest amounts of either of these oxides is greater than the minimum of either lime or magnesia. The rocks, as a group, show a marked alkaline character. Soda predominates over potash in every case.

The analyses have not been made uniformly in regard to the rarer constituents for in over half, these elements were not looked for. The analyses made in the laboratories of the United States Geological Survey without exception show small amounts of the rare elements. Doubtless these also exist in the other rocks. Of the minor oxides titanium is most noteworthy. It occurs in all of the rocks and varies almost indirectly with the silica content reaching a maximum of 3.20 in a nephelite-melilite-basalt from Black Waterhole in Uvalde County. Phosphoric acid is present also but in variable amounts.

Norms of the Igneous Rocks

	1	2	3	4	5	6	7	8	9	10	11	12	15	16
Orthoclase	29.47	34.47	32.80	27.80	5.56	16.68	22.24	7.78	3.89	6.12	3.89	------	------	------
Albite	23.32	13.10	14.67	11.00	24.63	23.84	14.67	12.05	18.34	13.10	------	------	------	------
Anorthite	------	------	------	------	30.30	8.34	4.17	23.91	21.13	17.24	11.12	11.95	15.85	------
Leucite	------	------	------	------	------	------	------	------	------	------	2.18	4.80	3.05	------
Nephelite	29.96	25.84	27.55	29.82	------	18.60	27.55	8.24	1.99	6.82	11.93	8.52	9.94	21.87
Sodalite	------	------	------	------	------	------	------	------	------	------	------	0.52	9.03	------
Sodium Silicate	0.24	1.22	------	1.83	------	------	------	------	------	------	------	------	------	1.59
Diopside	5.02	11.00	9.79	13.62	29.50	15.13	17.86	35.25	26.77	26.13	28.68	28.24	22.45	------
Olivine	------	0.44	------	------	1.43	4.18	1.56	3.70	16.10	20.05	26.75	31.27	23.34	31.88
Hypersthene	------	------	------	------	2.52	------	------	------	------	------	------	------	------	------
Wollastonite	0.35	------	0.70	0.70	------	------	------	------	------	------	------	------	------	------
Magnetite	------	------	0.70	------	1.39	3.94	4.87	5.10	4.18	3.94	6.76	6.26	5.34	2.32
Ilmenite	0.76	1.52	1.52	1.52	2.89	3.80	3.34	0.91	3.04	4.41	5.02	5.17	5.32	6.08
Hematite	------	------	------	------	------	------	------	------	------	------	------	------	------	------
Apatite	------	0.34	0.34	0.34	------	1.68	1.01	2.02	2.02	1.34	1.68	1.34	2.69	------
Acmite	7.39	7.39	6.93	9.24	------	------	------	------	------	------	------	------	------	9.24
Halite	------	------	------	------	------	------	0.47	------	------	------	------	------	------	------
Ackermanite	------	------	------	------	------	------	------	------	------	------	------	------	------	23.62
Total	96.51	95.32	95.00	95.87	98.22	96.19	97.74	98.95	97.46	99.15	98.01	98.07	97.01	96.60

Normative composition.—In the preceding table norms of the rocks with satisfactory analyses are given. The numbers at the head of columns correspond to the table analyses previously given and the norms of analyses from Washington's tables were secured from the same source.

Several features of this table merit attention. In general the norms of the rocks exhibit the same continuous variation seen in the analyses, though not to such a marked extent. Of the salic molecules, orthoclase and albite vary with the proportions of potash and soda present. Both are absent from the most basic rocks because of a deficiency of silica, their place being taken by an excess amount of nephelite and small amounts of leucite. Nephelite as a whole is quite prominent, emphasizing the sodic character of the rocks.

Diopside ranges from 5 per cent to more than 35, and is present in each norm, emphasizing an excess of lime in relation to alumina. Olivine is present in the norms of the more basic rocks and varies between fairly wide limits. The universal presence of ilmenite testifies to the constant presence of titanium in the rocks, reaching its greatest amount in the more basic ones. Acmite is present in the norms of the four rocks richest in soda.

Below is a chart modified after Cross,[23] showing graphically the variation of the principal normative minerals. It shows in another fashion the data recorded in the table of norms, the diagonal expressing variation of salic(Sal) and femic (Fem) constituents from 0–100 per cent. The amounts of the various minerals are laid off on the ordinates and the whole chart is divided into the classes of the C. I. P. W. classification into which the rocks fall.

Relation of norm and mode.—The relation of the norms of the rocks analyzed and the modes has already been indicated to a certain extent. For part of the minerals in some of the rocks there is a fairly close agreement while in others

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[23]Cross, Whitman, Lavas of Hawaii, U. S. Geol. Surv., Prof. Paper 88, pl. iv, 1915.

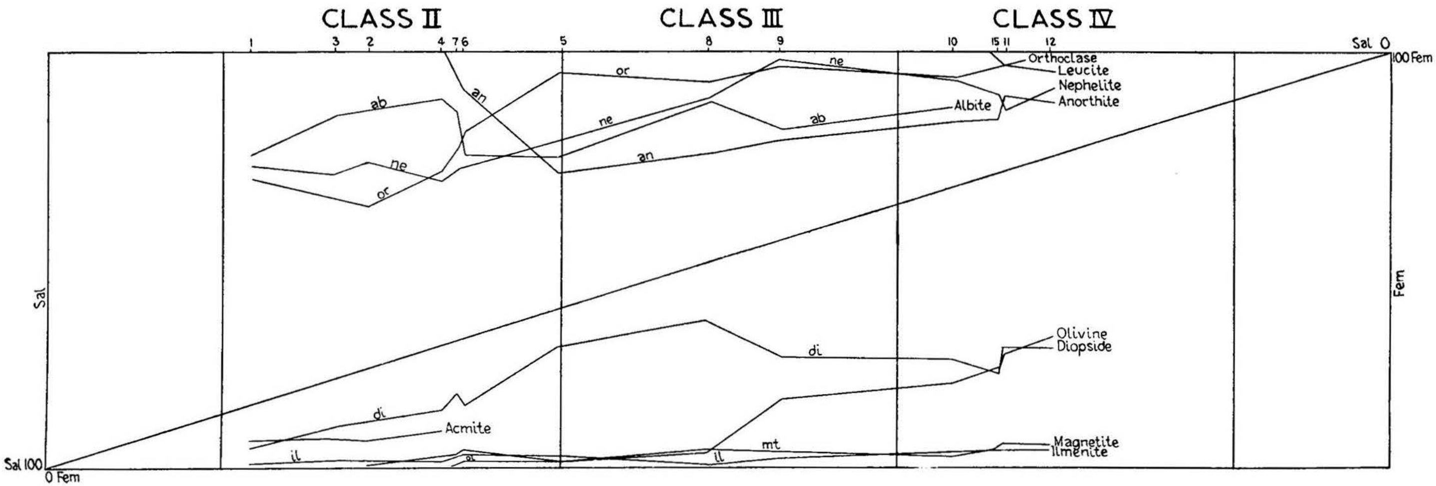

Fig. 11. Graph showing variation in amounts of normative minerals in the igneous rocks.

the normative minerals are not found in the mode. The normative orthoclase must be in close agreement with the mode, since potash can enter in only small amounts into the composition of other minerals. Plagioclase also in the rocks in which it is present must correspond fairly closely for beside augite the only minerals which might contain alumina and the alkalis are hornblende and biotite and these are present rarely. The augite of the one analysis available is low in alkalis but high in alumina. In the mode, only a few of the rocks actually contain the plagioclase, its place being taken by nephelite. Nephelite appears in the norms of all of the rocks except one and in the mode of all except four. Its presence is due on the one extreme to the richness in alkalis of the rock and on the other to the relatively small amount of silica. In the phonolitic rock some of the normative nephelite no doubt is modal aegirite-augite. Augite of the mode is included in the normative diopside which appears in all of the norms. Olivine probably corresponds fairly closely in norm and mode, appearing in both of all of the rocks except the phonolitic extremes. There is no normative molecular representations of melilite since its composition is not known. However, it is probably represented by sodalite and a part of the diopside and olivine.

CLASSIFICATION

The classification of the rocks under discussion in the qualitative and C. I. P. W. systems has already been made in the section on petrography. The designations in the C. I. P. W. system are here repeated along with certain ratios to show the relations of the whole group. The numbers of the rocks refer, as formerly, to the numbers in the table of analyses.

No.	Symbol	Name	Sal / Fem	$K_2O'+Na_2O'$ / CaO'	K_2O / Na_2O
1	(I) II.6.1.4	Laurdalose	6.0	----	0.53
3	II.6.1.4.	Laurdalose	3.7	----	0.53
2	II.6.1.4.	Laurdalose	3.3	----	0.53
6	II.6.2.4	Essexose	2.3	4.6	0.27
7	II.7.1.4	Lujavrose	2.4	9.9	0.21
4	II.7.1.4.	Lujavrose	2.5	----	0.39
5	II(III) 5.4.4	Hessose	1.6	0.52	0.45
9	III.5.3.4	Camptonose	0.8	0.64	0.16
8	III.6.3.4.	Limburgose	1.1	0.75	0.26
10	III" 6.3.4.	Limburgose	0.77	0.96	0.26
16	IV 1.4.2.2.	No name	0.28	----	------
15	IV 2.3.2.2.	Uvaldose	0.42	0.73	0.20
11	IV" 2.3.2.2.	Uvaldose	0.39	1.32	0.28
12	IV" 2.3.2.2.	Uvaldose	0.34	0.95	0.36

In this list no attempt is made to show transitions beyond the class, though in the case of Nos. 7, 8, 9, and 10 transitional relations are found in the order, rang or subrang. The rocks represented by the analyses fall within classes II, III, and IV with types transitional between I and II, II and III, III and IV, IV and V. The rocks as a group are strongly alkalic, especially with reference to the normative feldspars and lenads, though the greater number of proportionally of analyses of phonolitic rccks must not be forgotten. All of the rocks are dominantly sodic.

The names assigned are those of the subrang of the classification. No attention is paid to transitional rocks in this regard, though for some of these, compound names would probably be appropriate. It is to be noted that No. 16 bears no name. In the tables of the C. I. P. W. system no name is assigned this subrang (IV 1.4.2.2.) and no analyses corresponding to it has been recorded previous to this time. If the analysis is reliable a new rock type is apparently represented here. In computing the norm of this rock the ordinary rules of procedure would not apply in that molecules of soda and ferric iron ordinarily assigned to acmite were assigned to sodium metasilicate and magnetite to make the silica balance. It would be desirable to have a confirmatory analysis made of this rock because it is unusually low in alumina and high in soda for a rock of this type. Furthermore, potash is determined merely as a trace. Until the present analysis is confirmed it is thought unwise to consider the rock definitely as a new type to which a normative name is to be assigned.

RELATIONS OF THE ROCK TYPES

After reviewing the mineralogic and chemical characters of the rocks considered here, it seems difficult to escape the conclusion that they are related and show consanguinity. The fact that they form a series rather uniformly gradational and that special chemical characters are the same, leads to such a belief. They are to be classed as a group generally of a marked alkaline character and dominantly sodic. When to the chemical characters is added the evidence that all occur under the same tectonic conditions, it seems certain that they form a unit and that the region is to be classed as a petrographic province.

THE ORIGIN OF THE ROCK TYPES

A review of the evidence on the origin of the igneous rocks here described leads to a belief that they are related, are parts of a single petrographic province and are due to processes of differentiation. It seems reasonably clear that the various types were derived from a parent magma, the origin of which cannot be treated in the present paper. We are concerned here with the processes within the petrographic province that have produced the different igneous types of which the analyses may be taken as examples. The details of the differentiation cannot be positively stated because the considerations leading to them are theoretical. However, explanations are given which are believed to best fit the evidence available.

The problem presented is that of determining the nature of the parent magma, of the fractions from it, and of the processes involved in their derivation. The development of a theory to account for the origin of the various rock types must be in accord not only with the mineralogical and chemical data but also with the geological conditions. In the following discussion this is attempted.

Parent magma and the differentiates.—The actual composition of the parent magma of the region cannot be determined. It can be estimated from the analyses of the igneous rocks now found by taking averages. Even in this case there is chance for considerable error, because there is no accurate information as to the relative volumes of the different rocks represented by analyses. With these imperfections in mind the following averages have been prepared so that at least a general idea of the magma can be gained. In the table, *a* is the average of the superior analyses in the table of analyses previously given, while *b* is Daly's average world basalt. A rough estimate of the volumes of the various types represented by the complete table of analyses places olivine-basalt as most abundant, nephelite-basalt next, nephelite-melilite-basalt next, and phonolitic types last. An absolute average of the chemical composition of the rocks of the district would take this into account, but since the correction cannot be made with accuracy, it is not attempted. It must simply be noted that the average is based on a list of analyses representing disproportionate numbers of the various types of rocks, particularly the phonolitic ones.

	Analyses			*Norms*	
	a	*b*		*a*	*b*
SiO_2	46.49	49.08	Orthoclase	14.46	8.90
Al_2O_3	14.67	15.70	Albite	14.67	26.20
Fe_2O_3	3.19	5.38	Nephelite	15.62	------
FeO	6.23	6.37	Anorthite	9.45	24.46
MgO	7.52	6.17	Diopside	25.08	13.60
CaO	8.83	8.95	Olivine	7.80	1.70
Na_2O	5.17	3.11	Magnetite	4.64	7.89
K_2O	2.43	1.52	Ilmenite	3.04	2.58
TiO_2	1.69	1.36	Apatite	1.01	1.07
P_2O_5	0.46	0.45			

Rocks similar to the average *a* would be classed as *monchiquose* and would be slightly transitional, the symbol being "III 6.2.4. The world basalt of Daly is (II)III.5.3.4. being more salic than the average *a*. It is to be noted that the average *a* errs probably in being more salic than the average by volume of the rocks as they occur, since the number of analyses of phonolitic rocks is somewhat out of proportion. If the rocks of the district are derived from a common magma it was basaltic not far from Daly's world magma and corresponding generally to the olivine-basalts of the district. The rocks differing widely from the average *a* doubtless resulted from differentiation of the parent magma.

The analyses presented in the previous table no doubt are not sufficient to show all of the variations or differentiates present in the district. They must be considered as representative of classes of differentiates into which the rocks fall and record the differentiation which has taken place. As seen in the compiled list of symbols, the range is fairly broad and in a measure continuous. Six of the rocks are more femic than the mean, while eight are more salic. The reservation in regard to proportion of analyses to volume of rock must be applied here as previously. There is a rather uniform gradation from the salic extreme to the femic corresponding rather directly to the percentage of silica and not so directly with percentages of other oxides. The middle range of variation is occupied by nephelite-basalts and olivine-basalts, while the extremes are phonolites and nephelite-melilite-basalts or modified nephelite-basalts.

The process of differentiation.—A statement of the processes by which the various rock types originated could be made with more confidence if an order of intrusion could be established. As has been shown in another place, no definite age determination for the rocks can be made. As a group they are thought to be of Tertiary age, but as to the age relations between individual masses very little evidence exists. In one locality there are some data bearing on the matter and if conditions as seen there are representative of the general field some evidence at least is available.

In the area southwest of Uvalde and west of Nueces River there is an extensive occurrence of basalts. This area was mapped in the Uvalde Folio and is reproduced in this report as Figure 12. The general relationship previously discussed is as follows: A central area of olivine-basalt is bordered at four corners by bodies of nephelite-basalt and nephelite-melilite-basalt. As shown in the cross section in the figure, these basalts have intruded the olivine-basalt. There is no field evidence of intrusion in the ordinary sense. No contacts are determinable and exposures are not such as to reveal contact phenomena if these are present. The evidence for intrusion consists in a distinct difference in character of the rocks of the hills and in the topographic expression of the several types of rock. All specimens examined from the central low lying area are plagioclase-bearing rock, corresponding approximately at least, to the average postulated earlier in the report. There is no gradation between the plagioclase-bearing basalts and the non-plagioclase-basalts.

The hills of the more femic basalts stand distinctly above the central area, as shown by Figure 13, which is a view of Sulphur Mountain taken from the central low area. It might be argued that originally the basalt covered the central area up to the level of the top of the hills, erosion having produced the present arrangement. This is certainly not the situation because roof pendants of limestone are found today on the olivine-basalt area. Its present surface is approximately the limit of its original upper surface. It follows that the hills of more femic basalts standing high above must have intruded the central mass, a conclusion presented graphically long ago by Vaughan in the map and section mentioned.

In this area the nephelite-basalt and nephelite-melilite-basalt are younger than the olivine-basalt and represent products of differentiation at a stage more advanced than that which produced the latter. If the conditions found here can be extended to other parts of the Balcones region a reasonable explanation of the differentiation is at hand.

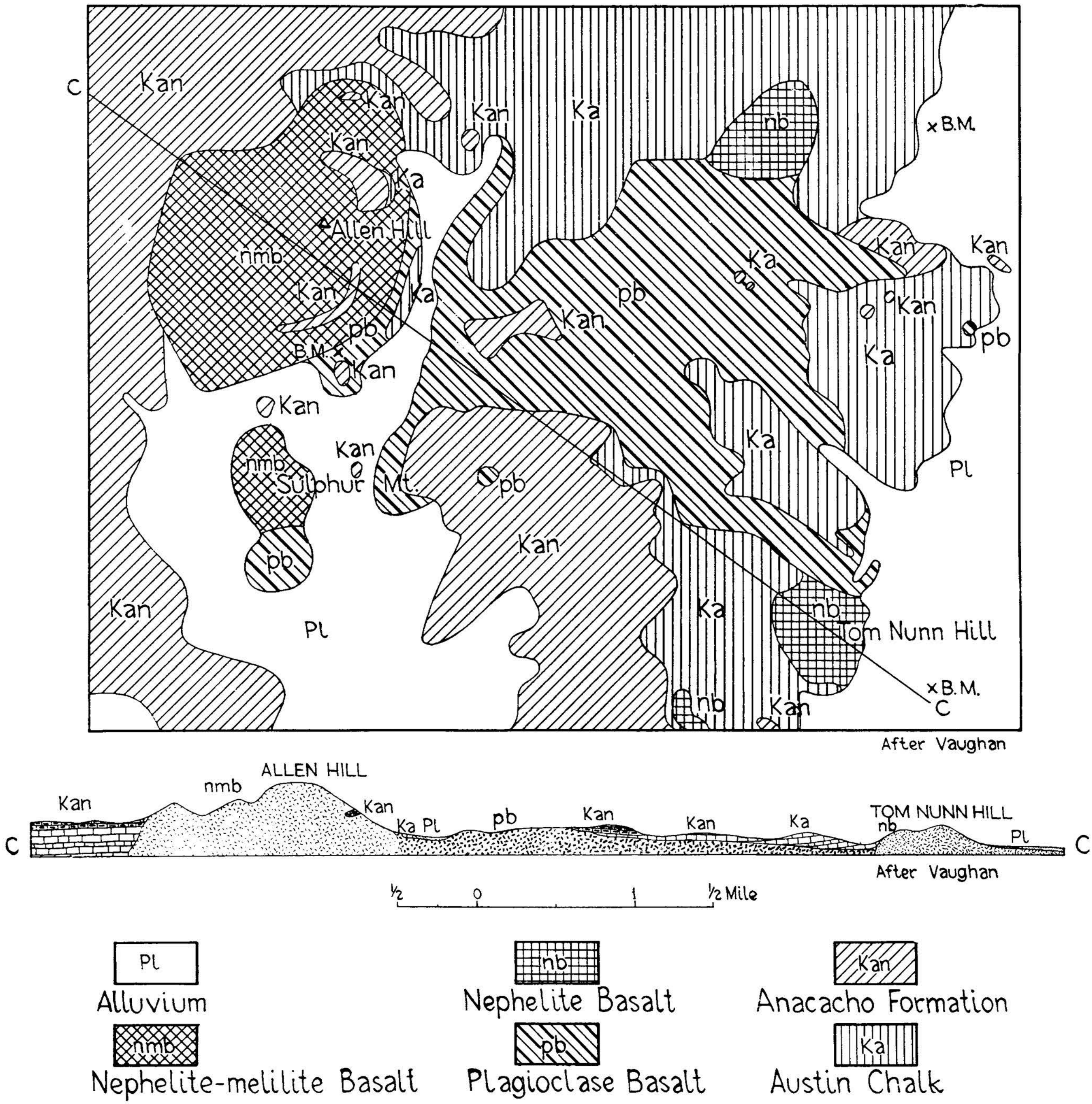

Fig. 12. Geologic map and cross section of the igneous area southwest of Uvalde, Uvalde County.

This would imply that the olivine-basalts, in general, were the earliest in time among the intrusions and that these were followed by the more femic varieties after differentiation had proceeded to a certain stage in the parent magma. Involved also would be the idea that the phonolitic rocks also are younger than the olivine-basalts because they differ from the olivine-basalts as much on one extreme as do the more basic ones on the other extreme.

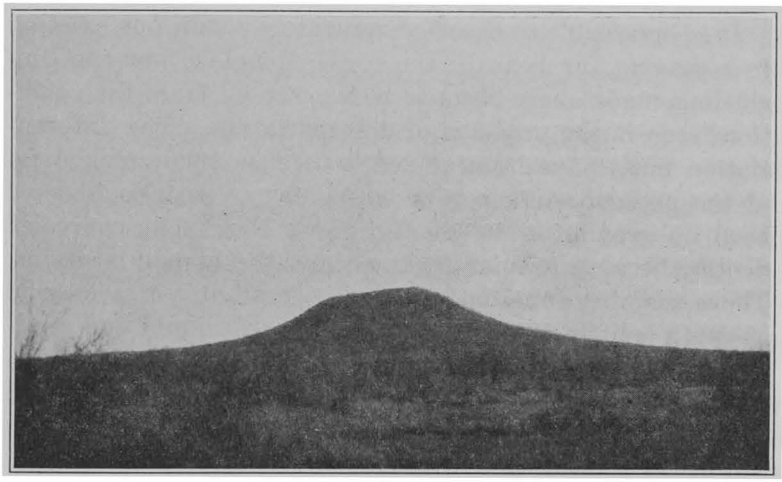

Fig. 13. View of Sulphur Mountain, southwest of Uvalde. This plug of nephelite-basalt intrudes a body of olivine-basalt, from which the view is taken.

The theory advanced for the origin of the igneous rocks is as follows: The region, because of similar geologic conditions and because of chemical and mineralogical characters of the rocks, is a petrographic province. Beneath the region under conditions unknown there existed a parent magma corresponding in a general way chemically to the olivine-basalt. Early intrusions from this parent magma consisted of olivine-basalts differing only slightly from the parent magma. With time, differentiations in the magma produced greater variation and the resulting intrusions were more femic on one hand (nephelite-basalt, etc.), and more salic on the other (phonolites). Chemically the rocks grade rather continuously from the olivine-basalt to the two extremes. The differentiation thus expressed was brought about primarily in the liquid parent magma before the present intrusions were accomplished. A certain amount of secondary differentiation occurred in the magmas of the present rocks before consolidation, but this was of a minor character. The differentiation is considered to be while the magma was essentially all liquid and not through the settling of crystals in a liquid fraction.

It is impossible to describe accurately conditions existing in a magma far beneath the present surface but the conclusions made above seem to be warranted from the conditions seen in the products of differentiation. The differentiation must have been at depth because small rock units at the present surface vary so widely. There could have been no graviative differentiation at slight but concealed depths, because heavier rocks occupy the higher positions. There remains apparently only the possibility of a magma at depth splitting into fractions while still liquid and sending off intrusions from time to time.

The secondary differentiation mentioned above refers only to minor variation within single rock masses. Here can be mentioned the pegmatite-like veinlets in the phonolite at Mt. Inge. These are very plainly due to differentiation in the phonolitic magma after it had reached its present position. Here also are to be found variations such as seen in Allen Hill in the area southwest of Uvalde, where melilite varies greatly in amount. Though these variations are distinct locally, they are not great enough to change the general character of the rock.

Along with the other areas of alkaline rocks of the world Daly[24] has discussed those of the Uvalde district. He has reproduced in his book the same cross section given here in Figure 12, omitting, however, the inclusion of Anacacho limestone in the side of Allen Hill.

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[24]Daly, R. A., Igneous Rocks and Their Origin, p. 422, 1914.

Daly's theory for the formation of the alkaline rocks is well known. It rests on the belief that basaltic magmas through assimilation of carbonate rock produce syntectic rocks of alkaline character. Conditions as seen in the field in the Texas region are such as to prohibit, apparently, the application of the theory to account for the origin of the alkaline rocks present. Assimilation of limestone with reference to those rocks if it occurred could be in two horizons. The present igneous rock bodies surrounded by limestones and intruded into them could conceivably have assimilated these rocks. In this connection attention is called again to the cross section mentioned before. It will be seen that Allen Hill, a mass of nephelite-melilite-basalt, contains inclusions of limestone. Similarly the low central area of olivine-basalt contains roof pendants of the same material. In none of these, as mentioned elsewhere, is assimilation demonstrable. If assimilation had occurred with resulting modification of the magma the rocks would not show the differences seen today. Assimilation at levels exposed today is hardly possible.

Conditions found in the region are also unfavorable for assimilation at depth. The lowest horizon stratigraphically where igneous rocks are exposed is the Glen Rose near the bottom of the Comanchean. The rocks exposed at this horizon show the great differences mentioned in the previous paragraph. Any assimilation occurring must have been below this level. At greater depths in the entire region, except for the first few hundred feet, the rocks consist largely of aluminous shales, sandstone and the pre-Cambrian basement. In other words, there is no available carbonate rock at depths in the entire region as shown by the logs of deep wells, in the files of the Bureau of Economic Geology. It is concluded that assimilation in the region is a negligible factor and that there is no reason to call upon it for the origin of the alkaline rocks. It seems much more reasonable to explain the alkaline extremes as differentiates of a regional magma.

An interesting feature of textural variation among the rocks is found in the occurrence of gabbro in the center of two of the basalts stocks, at Green Mountain and Mustang Waterhole, both in Uvalde County. Since these stocks are rather deeply eroded as compared with other occurrences, it is possible that they represent sufficient difference in physical conditions to account for the textural variation. If this is the case, it must be concluded that a difference in depth of burial of a magma of a few hundred feet can bring about great differences in the crystallization of the rock. The field evidence seems to show that the gabbros are simply textural variants of the basalt associated with them.

ALTERED IGNEOUS ROCKS

THE SERPENTINE

Mention has been made in previous sections of this report of serpentine or serpentine rock. This material is of great interest to the geologist because it constitutes the producing horizon in two oil fields, Thrall and Lytton Springs.[24a] In the present section of the report the geologic relations and origin of this material are considered. Considerable information on this subject has already appeared and has been consulted in this report. It is hoped by extending the scope of the discussion to furnish additional information that may be of interest and value.

History of serpentine.—Attention was first called to the serpentine by J. A. Udden,[25] though Vaughan[26] had mapped much of the material many years before in the Uvalde

[24a]As this report is going through the press a third serpentine oil field near Dale, Caldwell County, is being developed. Statements concerning the serpentine fields must be modified to include this late discovery. Brief notes on it will be found in another place in the report.

[25]Udden, J. A., Oil in Igneous Rock, Econ. Geol., Vol. 10, pp. 582–585, 1915.

[26]Vaughan, T. W., Description of Uvalde Quadrangle, U. S. Geol. Surv., Geol. Atlas, Folio No. 64, 1900.

district, calling it amygdaloidal basalt, and Hill[27] had also mentioned similar material in his paper on Pilot Knob.

The occasion of Dr. Udden's original note was the examination of samples from wells in the Thrall oil field which derived its production from the serpentine. Shortly after recognizing the character of the material at Thrall, Dr. Udden,[28] jointly with H. P. Bybee, described the Thrall field in detail including an extensive discussion on the nature and origin of the serpentine. By this time the name serpentine had become firmly fixed in the vocabulary of the driller so that it was thought best to retain it even though Udden and Bybee realized that the term might not be entirely appropriate. In the paper on the Thrall field, attention was called to Hill's early paper and to the several exposures of the serpentine rock in Travis County. It was stated that the materials of the exposures and of the Thrall field were essentially the same.

Despite the fact that Udden and Bybee called attention to the localities where similar bodies of rock might be found, no additional oil field of this kind was found until 1924 when the Lytton Springs field was discovered and developed. This occurrence of oil-bearing serpentine was described by H. P. Bybee and R. T. Short[29] and by D. M. Collingwood and R. E. Rettger.[30] In both papers there is a general agreement with the earlier explanation of the Thrall field by Udden and Bybee. Since the discovery of Lytton Springs a great deal of attention has been paid to the question of the occurrence of serpentine as a source of petroleum. A number of buried bodies of the material have been found, but up to the present time no additional

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[27]Hill, R. T., Pilot Knob, a Marine Cretaceous Volcano, Amer. Geol., Vol. 6, 286–292, 1890.

[28]Udden, J. A. and Bybee, H. P., The Thrall Oil Field, Univ. Texas Bull., 66, 1916.

[29]Bybee, H. P. and Short, R. T., The Lytton Springs Oil Field, Univ. Texas Bull. 2539, 1925.

[30]Collingwood, D. M. and Rettger, R. E., The Lytton Springs Oil Field, Caldwell County, Texas, Bull. Amer. Assoc. Petr. Geol., Vol. 10, pp. 953–975, 1926.

production has been secured from them. It is not unlikely, however, that still other fields of the type of Lytton Springs will be found if the search is continued.

Outline of discussion.—Since, as demonstrated by Udden, Bybee and others the serpentine is of igneous origin, it will be discussed in the present report. A survey of the igneous district from Williamson County to the Rio Grande shows that serpentine occurs under two and possibly three sets of conditions. Certain occurrences of the material surrounding bodies of massive basalt are the normal weathering product of those rocks, other serpentines are (in their present locations) purely sedimentary rocks, and it is possible that certain other bodies, as at Thrall and Lytton Springs, are the altered products of volcanoes active during Cretaceous times. In the present section of the report known occurrences of the material are listed, various types of occurrences are described, the petrography of the rocks is discussed and from these data some discussion of the origin is attempted. Finally remarks are made on the relation of the serpentine to the accumulation of petroleum. Data bearing on the serpentine bodies containing oil must be secured from drill samples and the actual field relations cannot be seen. Accordingly the part of the discussion relating to the origin of such masses and their relation to oil accumulation is not as complete as might be desired, and it is doubtful if a positive determination of the exact nature of some of the bodies of serpentine can ever be made.

Plate I, the map accompanying this report, shows in green the geographic distribution of the known serpentine bodies. There is a close correspondence in distribution with that of the massive rocks shown on the same map in red, and it is probable that they are parts of the same igneous activity. The belt in which the serpentine is found extends from Thrall in Williamson County to Uvalde County. The distribution is irregular throughout the belt, furthermore, part of the occurrences are not exposed at the surface having been encountered in wells. Geologically the serpentine bodies are all in the Cretaceous with the exception of one mass in the Comanchean (Edwards). The Eagle Ford, Austin, and Taylor formations contain bodies of the rock, though the relations are not the same. The list below supplements the map and in addition to giving locations of serpentine masses, includes notes on the conditions of occurrence.

GEOLOGY AND OCCURRENCES OF SERPENTINE

Atascosa County.—In northwestern Atascosa County serpentine was found in wells drilled by the Rio Bravo Oil Company. The wells, Cortinas 1 and 2 and Brown 1, encountered the material at 3244, 3199, and 3305 feet, respectively, beneath the surface. The thicknesses found were 77, 61, and 58 feet, and the horizon is apparently near the top of the Austin chalk. No confirmatory data are available on this occurrence but it seems likely that the material is sedimentary in nature, the rather constant horizon and uniform thickness leading to this conclusion.

Bastrop County.—In northwestern Bastrop County a number of wells encountered serpentine and it was expected that another serpentine oil field might be developed at this locality. The accompanying sketch (Figure 14) shows the location of the wells in reference to

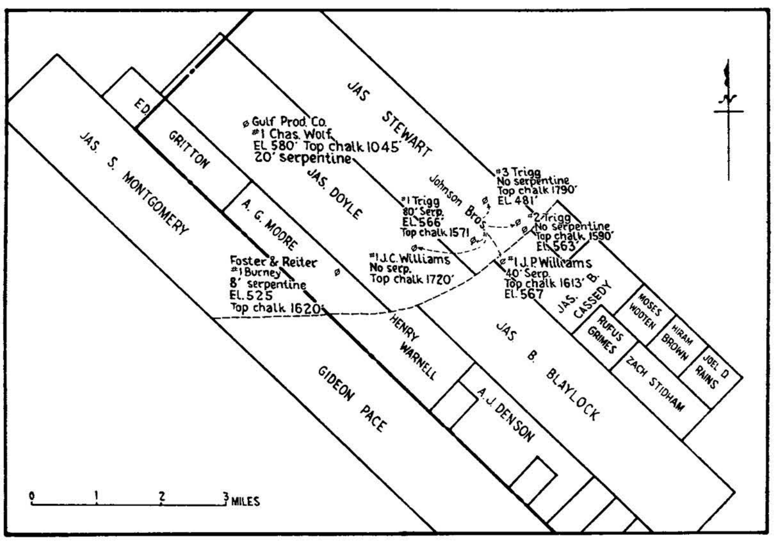

Fig. 14. Map showing wells in the serpentine area in Western Bastrop County.

survey lines found on the maps of the State Land Office. The sketch shows also the thickness of the serpentine, elevation of wells, and top of the Austin chalk where these data are available The irregular distribution of the serpentine is shown by the inclusion of some wells which contained no serpentine.

Johnson Brothers No. 1 Trigg, the initial well, encountered 80 feet of the material, reported to carry a trace of oil, at the top of the Austin chalk. This well was continued into the Edwards which was found at 2089. At 2092 in the Edwards samples containing serpentine mixed with the limestone were taken out. As far as known, this is the only occurrence reported up to the present time of serpentine from this horizon. It seems possible that the serpentine at this lower depth occupies the vent or passage which furnished the material to the Austin horizon. If so, the occurrences of serpentine at this locality in the Austin is of the type found at Lytton Springs.

To the northwest, northeast, and southwest, wells adjacent to Trigg No. 1 failed to find serpentine, but the Johnson Brothers' J. P. Williams No. 1 encountered 40 feet of the material. Foster Reiter No. 1, Burney, considerably to the south, had 8 feet of serpentine and the Gulf, Charles Wolfe, to the southwest, had 20 feet.

A consideration of the data suggests that two separate occurrences are recorded in these wells. The Trigg No. 1 well probably represents an occurrence of the Lytton Springs type, to be discussed later, while the serpentine of the Wolfe and Burney wells is probably sedimentary in character.

Bexar County.—In Bexar County no buried masses of serpentine are known and no surface outcrops of the material have been found. However, in many wells in the Somerset oil field, and generally in wells throughout the county, pebbles and fragments of the material imbedded in Austin chalk have been observed. The pebbles and fragments are usually less than one-half inch in greatest dimension and constitute less than one-fourth of any specimen seen. These pieces of serpentine apparently represent pebbles of the material furnished to the Austin chalk through processes of sedimentation.

Caldwell County, Lytton Springs.—The Lytton Springs oil field is located two miles south of Lytton Springs, in Caldwell County. The outcropping formations of the field and its vicinity include both Midway and Wilcox. These rocks possess a regional dip to the southeast, of approximately 150 feet to the mile. Within the limits of the oil field region a number of faults are known, and with the crop of the surface formations indicate a pronounced dome structure shown by drilling to extend down to the Austin chalk and perhaps even lower formations.

The producing horizon of this field is a body of serpentine encountered at a depth of 1200–1500 feet below the surface. The apparent size of the serpentine body is approximately 1.7 miles long by 1.25

miles wide with a thickness which varies between a few feet and an unknown amount, because certain wells were stopped after drilling several hundred feet of the material and before passing completely through it. The general horizon of the serpentine is the lower part of the Taylor marl and the upper part of the Austin chalk, with the greater thickness at depths normally occupied by chalk. Cross sections by Collingwood and Rettger show plainly the stratigraphic position of the serpentine. In considering these figures, however, it should be remembered that the lower neck-like portion of the serpentine body as figured is purely hypothetical, since no wells have penetrated to such depths.

The serpentine of the Lytton Springs field shows considerable variation in character. Specimens from the upper part are plainly of a sedimentary nature, showing well-defined bedding and containing foraminifera to a limited extent. Other specimens are massive but show under the miscroscope the fragmental character so common to the serpentine. Still other specimens, usually from the upper parts of the body though not found exclusively there, are fine-grained and may represent tuffs or altered ash beds.

A number of contact specimens of the serpentine and Austin chalk have been seen. None of these shows evidence of contact metamorphism, though Collingwood and Rettger[31] maintain that specimens seen by them show such effects. A contact specimen from M. L. Brewer well No. 1 of the Gulf Production Company at a depth of 1190 showed serpentine with sedimentary features in contact with fine-grained limestone slightly harder than normal Austin chalk. This core is shown in Plate IX. Such material shows no evidence of metamorphism and is reported to have yielded small fossils in specimens taken within 1 inch of the actual contact. The limestone lacks entirely the crystalline character found in numerous localities previously mentioned where the Austin chalk has been invaded by basalt. Judging from specimens available, any contact metamorphic effects in connection with this body of serpentine are of a very minor sort, and it is possible that the material reported by Collingwood and Rettger may have originated in some manner other than by metamorphism.

This body of serpentine is a cone-shaped mass slightly over a mile in diameter and over 500 feet thick in its deepest explored part. Its lithologic character varies considerably, top materials have a decidedly sedimentary aspect and there is little or no evidence of contact metamorphic effects.

Dale.—South and southeast of the town of Dale in Caldwell County another serpentine occurrence has been found. The location of the area is shown in the accompanying sketch (Figure 15). This centers around the E. L. Smith No. 1, Clingensmith well, east of Dale, where

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[31] *Op. cit.*, p. 963.

210 feet of serpentine lying just above the chalk was found. Southwest of this well the Foster Reiter No. 1 Brown found 112 feet of the material, but the Story No. 1 Jeffrys failed to show it. The Murchison-Fain No. 1 Miers, midway between the Brown and Clingensmith wells and to the northwest, contained 8 feet, while the Foster Reiter No 1 Dinges, south of the Brown well, had no serpentine.

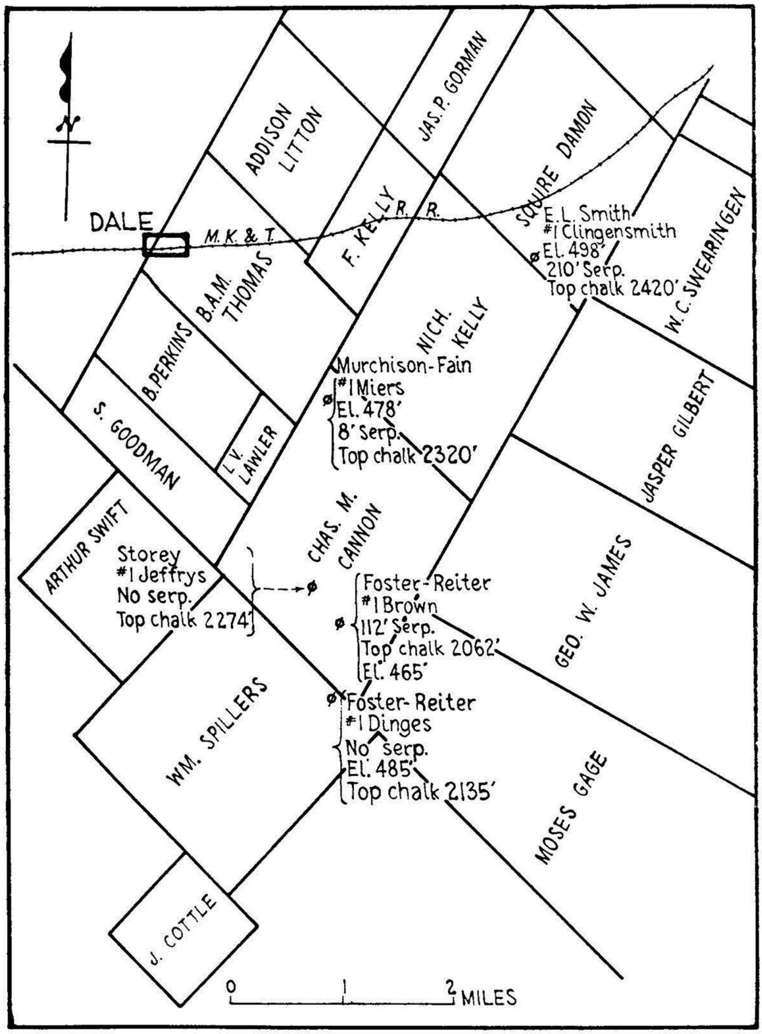

Fig. 15. Map showing wells in the serpentine area near Dale, in Caldwell County.

In these wells there is recorded apparently a large body of serpentine, the outline of which is not yet known. The material found in these wells in some respects is very suggestive of the Lytton Springs field. There is the same variation from fragmental material to serpentine rock containing sedimentary material. It is possible that the 8 feet of serpentine in the Miers well was entirely of a sedimentary character, but the rest of the occurrence apparently corresponds to the Lytton Springs type.

Figure 15 shows the wells in this locality drilled before April, 1927. Early in August, 1927, the Humble Clingensmith No. 2 was brought in as a producer so that this occurrence becomes the third serpentine field. As this report is going through the press the field is being developed. Details of the field beyond general facts are not now available.

Nine wells have been completed, some of which failed to produce. The greater number are south of the Clingensmith No. 1 shown in Figure 15, on the Damon Survey and adjoining tracts. The producing area is approximately 100 acres, except that one well is fully one-half mile east of the main producing group.

Insufficient wells have been drilled to outline the shape of the serpentine body, but it is known to be irregular. The discovery well with an elevation of 515 found serpentine at 2121 and stopped in serpentine at 2323. Other wells found 324 to 116 feet of the mateial except that dry holes found as little as 10 feet. The serpentine in all cases was at the top of the chalk.

The discovery well had an initial production of 9000 barrels, but within a few hours dropped to 2500 and soon to less than 1000. At the present time its production is less than 100 barrels. Other wells make about 35 barrels on the pump. Only two wells have flowed under their own pressure. In September, 1927, the field produced approximately 13,000 barrels.

The Bednor well No. 1, 7 miles southeast of Lytton Springs on the Ella Hill Survey, contained serpentine material at 1800 feet. This was probably similar to the serpentine in Bexar County. The Plateau Oil Company Chamberlain No. 1 well, 2 miles northeast of Dale on the Stephen Goodman Survey, contained some serpentine, but depth and other details are not known.

Guadalupe County.—Wells in Guadalupe County have yielded samples, from the Austin chalk, containing fragments of serpentine. These occurrences are similar in all respects to those of Bexar County already described.

Medina County.—In Medina County several occurrences of serpentine have been recorded and it was thought for a while that a new serpentine oil field might be developed. The occurrences are as follows:

1. About 1½ miles southwest of the station of Noonan on the Southern Pacific Railway an old well shows serpentine in the pit.

No data are available on this occurrence, but a well a mile distant, near Noonan, failed to find this material.

2. The Maxwell-Turman Neuman No. 1 well on the east side of Hondo River, southwest of Donlay and northeast of Elstone, encountered 90 feet of serpentine at the top of the Austin chalk. The elevation of this well is 793 and the depths of several horizons are as follows: Top of chalk, 785; base of chalk, 1103; base of Eagle Ford, 1127; base of Buda, 1214; base of Del Rio, 1281, and base of Georgetown, 1330. No specimens of the serpentine have been seen and no opinion as to the significance of this occurrence can be ventured.

3. Chicon Reservoir serpentine body. Around the reservoir made by impounding the waters of Chicon Creek a total of 8 wells have been drilled. These, with data on the serpentine encountered, are shown on the accompanying sketch (Figure 16). In the Shemmerhorn-San Anonio Trust No. 3, 440 feet of serpentine were encountered To the southwest, in wells of sufficient depth 100 feet and 40 feet, respectively, of the material were found. Wells to the southeast found no serpentine. There is indicated thus a rather large body of serpentine localized near the head of the Chicon reservoir and probably thickest to the northwest. As far as evidence is available, this occurrence seems to be of the type of Thrall and Lytton Springs, and it is possible that renewed drilling would locate oil.

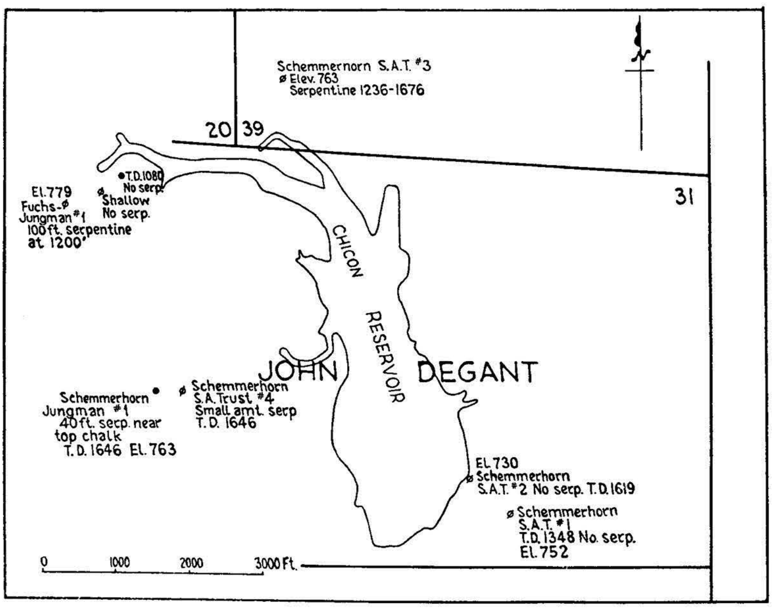

Fig. 16. Map showing wells in the serpentine area in Medina County.

Travis County: Pilot Knob.—Attention has already been called to the serpentine occurring as an alteration of the basalt at Pilot Knob. This material is simply a weathering product and is localized as a fringe around the Pilot Knob stock.

Onion Creek Localities.—In Onion Creek in the vicinity of Pilot Knob numerous occurrences of serpentine are found. These constitute some of the most interesting of all of the serpentine exposures and shed considerable light on the local geologic history of Austin chalk times. Prominent among the occurrences are many classed here as sedimentary. These are generally conformable with the Austin chalk above and below (though not so in all cases) and because of interbedding and the presence of fossils in some instances are thought to be definitely of sedimentary character.

The Austin chalk has not been zoned and no attempt has been made to trace out individual beds of the serpentine. However, it is believed that there is one fairly definite horizon of the sedimentary serpentine. This is shown in the canyon wall of Onion Creek directly north of Pilot Knob and upstream from the stream crossing on the Del Valle-Creedmoor road. Here in the wall of the canyon a zone of serpentine 10–15 feet thick is interbedded with chalk. It lies under a resistant ledge of chalk but grades into the chalk to certain extent both above and below. The material is dark green on fresh surfaces, but where weathered is brown to buff colored. In texture the serpentine varies from fine shale-like material to coarser conglomerate beds. Veining by calcite is a very common feature of the deposit; in some places fossils are abundant.

This particular ledge or bed of serpentine extends upstream for nearly a mile, where it can no longer be found. Very similar material is found near the mouth of Rinard Creek. Here again beneath a ledge of massive resistant Austin the beds of serpentine are found conforming to the description given above. It seems very likely that this is the same horizon exposed north of Pilot Knob and occasional exposures of the same sort are found at other points along Onion Creek.

The exposures near the mouth of Rinard Creek, beside exhibiting the general sedimentary character of the serpentine, show also some interesting data on the course of events during Austin times. The accompanying sketch (Figure 17) shows in a diagrammatic way the features found. In the right there are shown conditions which record folding and unconformity within the Austin formation. The upper serpentine beds are plainly unconformable beneath the ledge of chalk which forms the top of the section. A bed near the center of the section is continuous but the lower one pinches out against a folded or eroded portion of the chalk. Apparently these serpentine beds were deposited on an irregular Austin surface, then folded and planed off before the horizontal ledge of chalk at the top of the section was deposited.

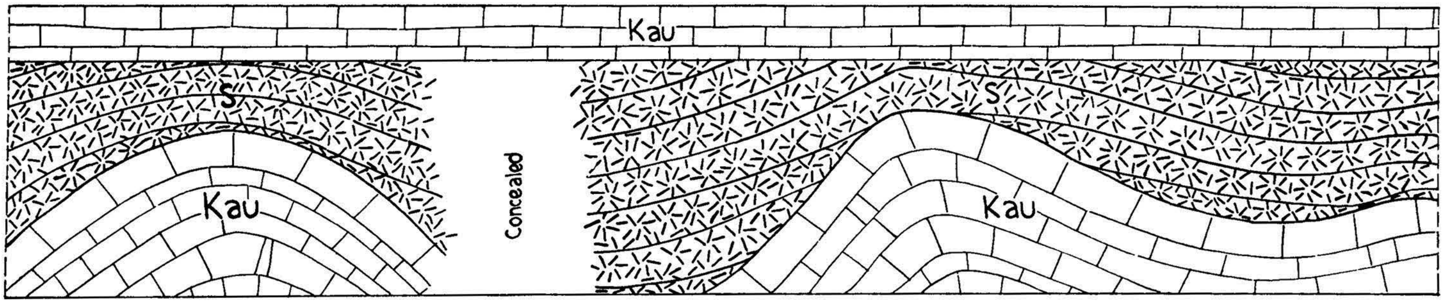

Fig. 17. Ideal cross section of serpentine exposures in Onion Creek, west of Pilot Knob. *Kau* is Austin Chalk. *S* is sedimentary serpentine.

In the central part of the section still greater irregularity in the section occurs. Here the lower serpentine beds are apparently channel-like deposits, having been deposited in a depression in the Austin chalk surface of that time. The beds again are planed off beneath the ledge at the top of the section

At the left of the section a fold in the Austin chalk is shown. This in its exposure is almost a dome in outline and is a very local feature. The fact that the top of the section only 15 feet above is perfectly horizontal is a striking feature. This section again carries serpentine beneath the massive upper serpentine. It is probable that the folding recorded here is due to the intrusion of an igneous mass below. If this is the case, the age of this intrusion is Austin, because the upper chalk beds are undisturbed. Apparently there was folding in Austin times producing local unconformities but not affecting the later beds.

Above the mouth of Rinard Creek still another unusual occurrence of serpentine is seen. This exposure apparently is not of a sedimentary nature and possibly represents an intrusion of basalt into the Austin. It will be seen from Figure 18 that an irregular dome-shaped mass of serpentine is shown in section within the Austin chalk. Immediately above the serpentine the chalk is folded to conform to the upper surface of the serpentine. Higher in the section the beds are horizontal. Within the mass of serpentine are many inclusions of chalk and many of these are pinkish in color, much harder than is usually the case and suggest contact metamorphism. These blocks of chalk included in the serpentine occur as isolated masses of Austin and appear as xenoliths.

The serpentine of this occurrence is variegated in character but a great deal of it is essentially massive. Some of the material is similar to that classed in this report as sedimentary but the occurrence as a whole does not show sedimentary characters. The occurrence seems to be an intrusion of basalt into the chalk, with later alteration to serpentine. This exposure is the nearest approach, at the surface, to conditions believed to exist in the serpentines of the oil field.

The folding of the Austin chalk shown in the above section is probably related to that found near the mouth of Rinard Creek and shown in Figure 17. If the dome in the Austin chalk shown there could be uncovered it is probable that conditions would be revealed similar to those just described. With this exposed serpentine mass accessible to examination, the explanation of the irregularities in the serpentine section are more readily explained and, as will be shown later, the local unconformities and folds are probably very significant in the history of the serpentine bodies, such as found at Thrall and Lytton Springs.

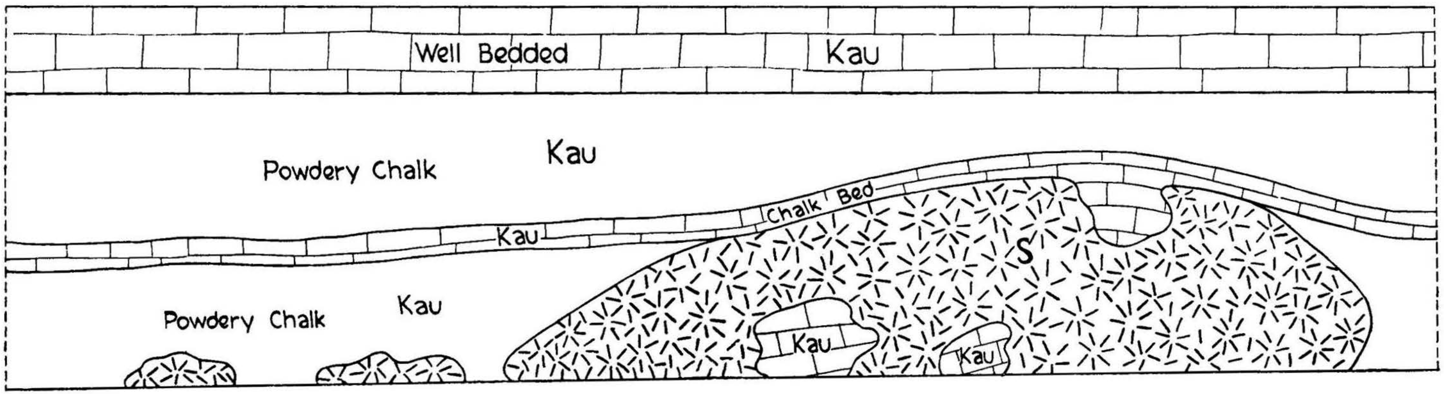

Fig. 18. Sketch of serpentine exposures in Onion Creek, above the mouth of Rinard Creek. *Kau* is Austin Chalk. *S* is serpentine, largely massive.

One-half mile upstream from Bluff Springs another exposure of serpentine is seen. Here two beds of serpentine 7 feet and 3¾ feet thick are found. These are dark green in color, very fine grained, and shale-like in character. They are definitely interbedded with the Austin chalk, and alternate with it. They are thought to be distinctly of a sedimentary nature. A small fault cuts the section.

At other localities along Onion Creek or nearby exposures of serpentine material are found. These are in most cases without distinctive character and not well exposed. As far as the scale of the map (Plate I) will permit, these are shown, and they are also shown in Figure 9.

Exposures of serpentine are found in South Austin, near St. Edward's College; near Kouns, on the Missouri Pacific Railroad, and near Pleasant Hill. These are shown in Figure 9. None of these exposures shows distinctive characters except the one near St. Edward's College, which contains abundant fossils and which apparently is largely of a sedimentary nature.

In eastern Travis County, near Littig, drilling has revealed the presence of variable amounts of serpentine in a number of wells. Data on this occurrence are shown on the accompanying sketch (Figure 19). It will be noted that an unusual thickness of serpentine was found in the Gulf Production Company No. 1 Carlson, there being 374 feet on top of the Austin chalk. The next greatest thickness was in the Humble Company No. 1 William Voelker, but in this well serpentine alternated with chalk as follows: Serpentine, 1066–1070; chalk, 1070–1097; serpentine, 1097–1100; chalk, 1100–1108; serpentine, 1108–1113; and chalk, 1113–1214. The Lockwood well showed no serpentine, and Gulf Parsons No. 1, far to the south, contained only 4 feet.

Apparently a rather large buried mass of serpentine is involved here, centered approximately around the Gulf Carlson well and the Humble W. F. Voelker. To the east the serpentine thins to 32 feet in the Anna Giese well and is absent in the Lockwood well. To the southeast the Humble W. N. Voelker shows alternating chalk and serpentine probably entirely sedimentary. The Gulf-Parsons, in which 4 feet of the material was found, is too far from the central area to be of significance and probably contains only a small bed of sedimentary serpentine. It is reported that this occurrence of serpentine is shown in surface geological features in somewhat the same way that the Lytton Springs mass was shown. If this is the case, additional drilling should show a mass of serpentine analagous to that at Lytton Springs. It seems likely that such a mass exists and that its possibilities from an oil production standpoint have not been exhausted.

Uvalde County.—Uvalde County, along with Travis, furnishes the most abundant exposures of the serpentine rock. Reference to the map (Plate I) will show the location of the occurrences of sufficient size to appear on the map. A few occurrences of the material are known from wells and no doubt more would be known except for the fact that relatively few wells have been drilled.

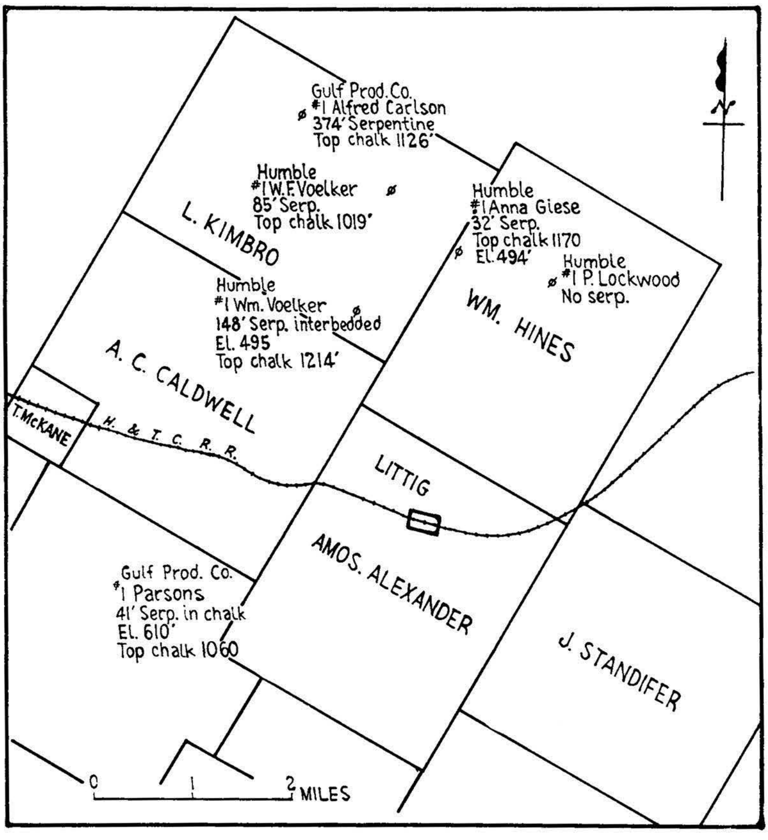

Fig. 19. Map showing wells near Littig in Eastern Travis County.

The principal exposures of the material are found on Blanco and Frio rivers, though numerous other isolated occurrences are known. In general the present discussion is confined to the sedimentary serpentine and not that which is found as a weathering residue. The latter type is common in connection with the igneous masses of Uvalde County, and attention has already been called to the material at Knippa. Many similar exposures are known representing the weathering product *in situ* of the massive basalt.

The serpentines of Uvalde County, whose relationships can be determined excepting the weathering residue, are apparently of sedimentary nature. They are found in exposures along the banks of Blanco and Frio rivers, south of the Southern Pacific Railroad, nearly to the Zavalla County line.

In Blanco River the most noteworthy exposure is immediately downstream from the railroad crossing, where for nearly a mile the material is exposed in a bed about 10 feet thick. The rock is dark to light greenish in fresh surfaces, and well stratified. It is apparently located immediately above the Austin chalk, since it is overlain by Anacacho limestone. Near the railroad crossing, this material is again shown and here is exceedingly well stratified and at the same time folded, dipping to the northeast.

In Frio River the most noteworthy exposures are at Black Waterhole and farther downstream, in the vicinity of Conner's Ranch. The Black Waterhole locality has been described previously in Figure 5 shows the conditions existing. The serpentine for the greater part is in definite beds and interbedded with thin calcareous layers. Certain beds are coarsely conglomeratic, containing, in addition to boulders of serpentine, boulders and cobbles of limestone and sandstone up to 1 foot in diameter. From this exposure a colony coral over 1 foot in diameter was secured. There is considerable alternation in the beds of the serpentine, some being fine, well sorted in materials, while others are coarse and poorly sorted. Furthermore, in some parts of the section the bedding is not distinct, but in others, as can be seen from the illustrations (Figures 3, 4, and 5) there is a distinct sedimentary bedding present.

The occurrence of pebbles of limestone and sandstone and the lithologic character and structure of the deposit are thought to definitely show its sedimentary nature. It represents, if the present interpretation is correct, a near-shore deposit derived from the erosion and weathering of a basalt mass with which must have been exposed also limestone of lower Cretaceous formations. The age of this sedimentary serpentine is probably Eagle Ford.

The relation of the serpentine deposit to the massive igneous rock has already been mentioned. Reference to the figures already cited will show that the igneous rock intrudes the serpentine and that the latter has been subjected to folding, probably coincident with the intrusion. The deposit is the oldest known material of this sort in the entire Balcones region and perhaps sets a beginning time for igneous activity and faulting in the Balcones region.

The deposits of serpentine near Conner's Ranch, while extensive, are not so well exposed as that at Black Waterhole. In the stream bed for 1½ miles above the ranch as much as 25 feet of the material can be seen. It is roughly stratified and contains pebbles of limestone. Available data indicate that the occurrence is of a sedimentary nature and its relation to the other sedimentary rocks has not been determined.

The Conner's Ranch locality is noteworthy for one feature not found elsewhere. Here the serpentine has been intruded by phonolite plugs. This is of significance because by no conceivable type of alteration could the serpentine be derived from phonolite. There is no possibility that phonolitic volcanoes threw out the serpentine as fragmental material. Accordingly, the serpentine here gives a hint as to the age of the younger igneous rocks.

Williamson County.—The Thrall oil field in Williamson County furnishes the principal occurrence of serpentine in the county. The field has been described in reports already cited and the general features reported are reviewed here.

The field is located 1 mile southeast of Thrall, which is a small town on the Missouri Pacific Railroad. The surface rocks are the Taylor marl, probably the upper part of the formation. Development of the field revealed that the oil was derived largely from a mass of serpentine rock which was recognized here for the first time. Examination of well logs and cutting of the field led Udden and Bybee to conclude that the igneous rock or serpentine was enclosed entirely within the Taylor marl, the upper surface of the Austin chalk being about 240 feet below the bottom surface of the serpentine, though in one place the serpentine was only 10 feet above the Austin.

One significant feature of the serpentine mass is the character of the sediments immediately overlying. This material spoken of as "cap rock" is of three sorts—shell breccia, clay, and calcareous sandstone. Udden and Bybee consider these to be of significance in discussing the origin of the serpentine occurrence.

From the structure map in the original Thrall report it is seen that the shape of the buried mass of serpentine is roughly that of a cone. The scale employed exaggerates the height and steepness of the slope, but there is a very pronounced cone shape present despite this fact. A study of the maps and figures given by Udden and Bybee shows that the actual shape of the mass is a dome with minor irregularities. The bottom contour of the body is irregularly funnel shaped. The area of the igneous rock is a little less than 1 square mile, while the thickness varies between a few feet and 547 feet.

The material from wells in the Thrall field showed some variation in composition. The greater part is the fragmental type, with fragments up to one-third inch in greatest dimensions. This type was derived from the alteration of melilite-bearing basalt. Another type is very fine grained and dark green in color. Certain specimens of this material show structures suggesting a tuff or other volcanic deposit. A third type of material is a mixture of serpentine and marl containing foraminifera and is found usually near the upper surface. Illustrations of the Thrall serpentine are shown in Plates VII and VIII.

Zavalla County.—In northern Zavalla County a number of wells are reported to have encountered serpentine. Exact data on these occurrences are not available, because of failure to recognize the serpentine during drilling in some cases and because samples are not now available from the wells which were drilled several years past. Notes on the wells from which serpentine was reported are given below. These include also two wells from the Pulliam Ranch in southern Uvalde County, near the Zavalla-Uvalde county line.

Gulf Production Company C. L. Bloom et al. No. 2 Anderson. Located at west end of railroad bridge across Nueces River, near Pulliam. Drilled in 1920. The log of this well shows green shale 200–265, 240–255, 365–370, basalt at 650–654 and 684–6687. Cuttings of serpentine and basalt were collected from the old dump of this well and are thought to be the green shale and basalt of the log. Apparently at approximately the Austin horizon several layers of serpentine were encountered, while at greater depths sills of unaltered basalt were found.

Gulf Production Company C. L. Bloom et al. No. 1 Pulliam, near Pulliam Siding on the Pulliam Ranch. The log of this well fails to show serpentine, but cuttings of both serpentine and basalt were collected from the dump. The same is true of another well (name unknown) about 500 yards from the above.

National Refining Company Nos. 1 and 2 Pryor. These wells are located northeast of La Pryor, near Nueces River, and 7000 feet apart. In No. 1 from 840 to 1649 serpentine, interbedded with shale and sand, was encountered. The lower 450 feet of the serpentine was essentially pure and not interbedded. In No. 2 the serpentine was found from 1216 to 1885, with the upper part again being interbedded. The horizon of the material is reported to be immediately above the Austin.

Other wells in the same district reported to have serpentine were Old Dominion No. 1 Pryor, Sun No. 1 West, and La Pryor Oil and Gas Company No. 1 Pryor. Data on the serpentine in the latter wells are lacking, but in general the log fails to show the material, it usually being reported as green shale.

Evidently two serpentine occurrences are indicated by the Zavalla County wells. The material found at the Pulliam Ranch is in relatively thin beds and nothing can be stated as to its nature. The serpentine in wells on the La Pryor Ranch, as shown by the wells of the National Refining Company, is probably an extensive occurrence, since the two wells encountered great thicknesses of the material. Although no exact details of the occurrence are known, it is probable that the serpentine in these and the other wells nearby is part of a mass such as found at Thrall and Lytton Springs.

PETROGRAPHY OF THE SERPENTINE

The petrography of the serpentine found at Thrall and Lytton Springs has been treated in the bulletins and reports describing those fields. The descriptions which embody the observations of a number of petrographers are in general agreement as to the character of the rock. There are, however, differences of opinion as to the interpretation of the rocks examined, and it is this aspect of the problem that is most important in determining the history of the various serpentine occurrences. The present work can add only certain details in regard to the petrography and can make no great revision of the descriptions already made.

Megascopic character.—In a general way it can be said that all of the serpentine, whether formed as a weathering product, as a sedimentary rock or otherwise, is similar. It can be described as a dull greenish fragmental rock composed largely of serpentine and chloritic minerals. There is, however, a considerable variation among the specimens of the material, as will be noted in the following paragraphs.

Microscopic characters.—The microscopic characters of all the variations of serpentine are difficult to determine completely because of the nature of the material. Some of the specimens are very soft and incoherent so that sections are prepared only with difficulty. The denser, more resistant varieties, however, are readily sectioned and yield considerable information concerning the nature of the rocks.

By far the greater number of specimens examined show a fragmental texture and this is often apparent without the aid of the microscope. Rounded to irregular bodies of serpentinous material are observed imbedded in a ground of homogeneous frequently lighter colored serpentine. In such textures the fragments represent pieces of the original rock and in them occur numerous pseudomorphs after the original minerals of the igneous rock. Illustrations of the various textures are found in Plates VII and VIII. The fragmental texture is one of the most characteristic features of the serpentine and at the same time one of the most perplexing. It may represent the original fragmental texture of an agglomerate, or it may represent a texture produced by alteration of an entirely massive rock. Up to the present time no method of deciding this point beyond doubt has been found for the serpentines in buried masses, as at Thrall and Lytton Springs, and it is believed that a texture of this sort could be produced in either way.

Serpentine, such as found at Knippa and Black Waterhole in Uvalde County, presents no problem as to origin. In the one case the material was derived from alteration *in situ* of nephelite-basalt, while in the other it is a true sedimentary rock and has sedimentary rock structures. In thin sections specimens from these localities show the same features as those of Thrall and Lytton Springs, and the texture which is now fragmental may be of absolutely no significance in a discussion of the origin of any given body of serpentine.

In the serpentine of Lytton Springs and Thrall the fragmental particles attain a maximum size of about 8 mm. and range down to particles less than 1 mm. in largest dimensions. In the sedimentary serpentines exposed at the surface, it is not uncommon to find the fragments as much as a foot in diameter where they represent boulders or cobbles of the original rock.

A considerable number of the specimens of the serpentine are very even-grained and do not show the fragmental texture mentioned above. This is true at Lytton Springs, at Thrall and in specimens from other localities. Such material is fine-grained, showing minute particles of serpentine and other secondary minerals and occasionally detrital minerals such as quartz. Although such material is found at various levels in the serpentine mass, noteworthy occurrences are at the upper surfaces of the body and from these places small fossils have been obtained. This material represents either a sedimentary rock akin to shale or is a fine-grained tuff deposited in water.

The presence of glass has been mentioned, usually by inference, in the various reports on the Thrall and Lytton Springs serpentines. During the present work no glass or structures residual from glass have been observed. It is very doubtful if basic glass could survive the alteration the rocks have undergone. The groundmass of the fragments mentioned previously could well be mistaken for glassy material, but there is no evidence showing that such was its nature. However, textures of the fine-grained serpentines do suggest the character of a tuff bedd. These are shown in Figure 2, Plate VIII.

The serpentine rocks contain a number of distinct minerals. These for the most part are secondary in origin. Frequently they show by pseudomorphous outlines the natures of the minerals composing the original rocks from which serpentine was derived.

Serpentine is the most abundant mineral of the rock and specimens from all localities contain it. It is developed as a pseudomorph after olivine, melilite and other minerals, as spherulites and as a general groundmass mineral. The serpentine of the pseudomorphs is the most striking since perfect crystal outlines of original mineral are frequently preserved. In the case of serpentine pseudomorphs after olivine the net-like appearance characteristic of this alteration is common, greenish fibers and plates of the mineral being perpendicular to crystal boundaries and cracks. In the rocks examined only rarely are remnants of original olivine preserved. Usually the alteration has been complete. Replacements or alterations of melilite to serpentine appear to be more or less uniform with no development of fibers and plates of the mineral. Plates VII and VIII show pseudomorphs of serpentine after both olivine and melilite.

The serpentine of the groundmass is very finely crystalline, light green in color. In most instances it appears as a uniform matrix material inclosing the denser, darker fragments mentioned previously. The spherulites of serpentine occur both in the groundmass and in the fragments. They are rounded crystalline bodies containing numerous fibers and plates of serpentine set perpendicularly to the wall of the spherulite. These exhibit aggregate polarization and frequently show a cavity in the central portion. In specimens from the Johnson Brothers Trigg well in Bastrop County groundmass material showed a general spherulite condition in which serpentine fibers are arranged around centers but in which no boundary spherulite walls are seen. Associated with these, however, are numerous spherulites as described above with definite boundaries.

The following varieties of serpentine have been identified in the rock by various observers: Chrysolite, picrolite, bowlingite, iddingsite, and deweylite. It is probable that the most abundant variety is chrysolite, but the presence of the other varieties is not unusual since the original rocks of the various serpentine bodies were somewhat variable in composition and all contained minerals, such as olivine and augite, which alter readily to one form or other of serpentine.

Chlorite has been mentioned in many descriptions of the serpentine rocks and one observer at least has given it a place of first importance among the minerals present. It is believed that this mineral is of entirely subordinate importance in the greater number of samples of serpentine rock from the various localities. Only an occasional area exhibits the pleochroism and other optical properties diagnostic of the mineral. It occurs to a limited extent, as pointed out by Hanna,[32] in the groundmass of specimens from Lytton Springs.

[32]Bybee, H. P. and Short, R. T., *op. cit.*, p. 18.

Magnetite occurs as dust-like particles scattered through the area of thin sections of the rocks. Apparently most of this mineral has been derived from the alteration of olivine since the grains are different from the primary magnetite grains of the massive basalts.

Calcite is abundant in certain specimens of the serpentine rock. It occurs almost entirely as a vein material or matrix mineral, though the centers of a few spherulites of serpentine are occupied by grains of the mineral. For any given large serpentine mass, calcite is most abundant in the upper part of the occurrence where it very clearly has been deposited from solutions. It is not uncommon to find the mineral to a limited extent throughout entire serpentine bodies. In the sedimentary serpentine masses calcite becomes very prominent. Since these deposits were aggregated in a limestone forming sea, the deposition of large amounts of calcite as cement material is to be expected. In deposits of serpentine of all sorts exposed at the surface jointing is a common feature and very often the joints are filled with veins and veinlets of calcite. These are due to the work of solutions which circulated through the joints after the serpentine rock as a unit was formed.

It is probable that a part of the carbonate mineral of the serpentine rock is siderite. In many specimens the effects of weathering of the carbonates indicate that the mineral contained considerable iron. Probably such carbonate is siderite rather than calcite. In specimens from the Thrall field the presence of minute rounded particles of a highly refractive mineral is common. These were thought by Baker to be titanite. Larger particles and even crystals of the same mineral are also occasionally seen. Pyrite occurs rarely in scattered particles through the rock mass. It is a product of mineralizing solutions operating subsequent to the formation of the serpentine mass. Zeolites were mentioned by Tomlinson[33] in his observation on the serpentine from Thrall. If present these occur

[33]Udden, J. A. and Bybee, H. P., *op. cit.*, p. 36.

in very minor amounts, since they were not seen during the course of the present work.

Chemical composition.—It is to be regretted that no great amount of information on the chemical composition of the serpentine rocks is available. The anlyses available number only thirteen and they do not represent a great number of occurrences of the material. Furthermore, the analyses are not as complete as might be wished. The following table gives all of the analyses of Texas serpentine available at the present time.

The analyses given in the table are inadequate for a complete study of the chemical character of the serpentine rock. The deficiencies fall into two general classes: minor constituents were not reported and the samples are not representative of large parts of the various rock bodies. In addition, only four of the serpentine occurrences are represented in the table. It would be desirable to have complete data on the amounts of CO_2, SO_3, P_2O_5, TiO_2, H_2O+, H_2O- and to have the iron oxides divided into ferrous and ferric. This has not been done uniformly in the analyses so that differences between certain analyses are apparent rather than real. The serpentine bodies vary greatly in composition from place to place so that a great variation in abundance of the various constituents is to be expected. The analyses, however, show the general character of the rock and if the discrepancies in the several cases are allowed for, the course of the alteration which produced these rocks can be understood.

The analyses as a group show that the serpentines correspond to basaltic rocks that have lost silica and have gained carbon dioxide and water. The addition of carbon dioxide and water are to be expected in the rocks both on account of weathering and because of deposition of secondary calcite from solutions. In the formation of the serpentine minerals hydration is the dominant process so that the addition of water is the normal event. In the table on page 136 an attempt is made to show quantitatively the course of the alteration of the igneous rocks to produce serpentine. This

Analyses of Serpentine

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	33.52	31.55	27.30	32.40	32.00	32.70	27.20	31.00	34.90	31.50	27.00	20.74	28.12
Al_2O_3	21.44	19.69	23.90	22.44	8.59	13.42	8.51	8.41	8.00	10.15	11.47	10.21	4.32
Fe_2O_3	14.36	12.44	9.70	12.76	9.04	6.45	12.14	5.36	7.90	9.58	8.89	14.04	8.62
FeO	------	------	------	------	5.35	8.21	5.00	10.00	6.56	4.14	4.28	2.86	3.37
MgO	9.06	11.08	7.48	8.06	12.38	11.23	9.27	15.19	13.57	14.24	5.58	3.11	15.37
CaO	6.07	5.96	11.90	7.14	10.61	6.51	13.10	12.69	3.02	6.76	14.25	20.48	12.54
Na_2O	2.32	0.04	------	------	0.77	1.81	0.84	0.05	12.05	0.29	0.40	0.30	4.24
K_2O	0.05	0.08	------	------	0.16	0.21	0.19	0.14	0.32	0.10	0.21	0.41	trace
CO_2	1.92	------	9.35	5.61	------	------	3.30	------	------	------	4.40	10.00	------
SO_3	1.92	2.77	0.86	0.69	------	0.93	0.04	------	------	0.55	0.48	0.62	------
P_2O_5	------	------	------	------	1.12	1.61	0.87	1.40	0.19	0.51	0.64	trace	1.77
TiO_2	------	------	------	------	0.80	0.80	0.21	0.80	------	0.56	0.75	0.52	2.56
H_2O+	------	------	------	------	11.40	8.37	7.16	5.10	------	12.52	10.86	8.90	15.13
H_2O-	------	------	------	------	7.40	8.18	12.50	5.90	------	9.44	11.30	8.10	4.30
Ig Los	13.20	15.64	9.21	10.53	------	------	------	------	12.42	------	------	------	------
Total	99.79	99.25	99.70	99.43	99.62	100.38	100.33	100.52	98.93	100.34	100.46	100.29	100.34

1–8. Altered igneous rock of Thrall Oil Field, Univ. Texas Bull., 66, pp. 40–41, 1916.
9. Altered igneous rock of Lytton Springs Oil Field, Univ. Texas Bull. 2539, p. 14, 1926.
10–12. Altered igneous rock from Onion Creek, Travis County, Texas, Univ. Texas Bull. 66, p. 52, 1916.
13. Serpentine rock, Black Waterhole, Uvalde County, Texas. J. E. Stullken, analyst.

is based on the assumption that an average of analyses of the Texas basalts corresponds fairly closely to the rock from which the serpentine was derived and that an average of serpentine analyses can be taken as representative. To establish exactly the course of events in the formation of serpentine would require a knowledge of the individual rock mass which altered. Since this information is not available recourse is had to the nearest approach to conditions existing during the formation of the serpentine.

In the table the average of fresh basalts is contrasted with the average of serpentines. Under Nos. 2, 2a, 3 and 3a similar comparisons for the weathering of a basalt beneath a bog and the surface weathering of diabase are given. In each instance the third column shows the number of grains of altered material required to furnish an equal amount of the respective constituents found in 100 grams of fresh rock. The average serpentine in comparison to the average basalt has lost silica, ferrous oxide, magnesia, lime, soda, and potash, while it has gained alumina, ferric oxide, phosphoric oxide, titanium oxide, water and iron. In the serpentine 132.28 grams of the rock are required to furnish the same amount of silica found in 100 grams of the average Texas basalt, while on the other hand, only 84.85 grams of the rock are required to furnish the amount of alumina in 100 grams of the basalt. Similar comparisons can be made for the other constituents. The figure given for CaO in the serpentine may be low, since it represents total CaO less an amount needed to combine with the amount of CO_2 present in the original analyses.

The three pairs of analyses are shown in another way in the accompanying graph (Figure 21). Since of all major constituents alumina is usually the most constant, the graph permits a comparison of each constituent in terms of alumina. No. 1 is the pair of analyses from the basalt average and serpentine. With respect to alumina, silica was lost during the alteration, for 132.28 grams of serpentine are required to furnish the same amount of silica in 100 grams of fresh rock, while only 84.85 grams are required

Comparison of Fresh and Altered Basaltic Rocks

	1	1a		2	2a		3	3a	
	Fresh	Altered	$\frac{Fr}{Al}\times 100$ (1)	Fresh (2)	Altered (2)	$\frac{Fr}{Al}\times 100$ (1)	Fresh (2)	Altered (2)	$\frac{Fr}{Al}\times 100$ (1)
SiO_2	42.94	32.46	132.28	45.21	59.98	75.3	43.56	44.93	97
Al_2O_3	11.71	13.80	84.85	7.82	11.50	68	14.58	16.27	89.6
Fe_2O_3	3.44	9.52	36.13	3.41	2.42	141	3.84	13.37	28.7
FeO	8.21	5.78	142.04	8.08	1.86	435	7	0.0	------
MgO	12.03	10.99	109.46	8.43	0.75	1123	9.95	6.40	155.3
CaO	12.60	2.80	435	12.31	2.80	440	10.78	1.84	586
Na_2O	3.18	2.30	138	6.64	1.18	563	1.86	2.03	91.7
K_2O	.83	0.17	488	2.94	1.48	199	1.02	0.84	121.5
CO_2	------	------	------	------	------	------	1.93	------	------
SO_3	------	0.24	------	0.56	0.21	------	------	------	------
P_2O_5	0.57	0.94	60.63	------	------	------	------	------	------
TiO_2	2.19	0.90	24.33	------	------	------	1.03	1.34	77
H_2O+ / H_2O-	1.87	13.85 / 8.77	8.22	1.82	16.53	11	3.85	12.55	30.7
Fe	9.37	11.14	84.11	8.69	3.14	276	8.15	9.37	87

1, Average of Texas basalts; 1a, average of serpentines; 2 and 2a, fresh and weathered basalt; 3 and 3a, fresh and weathered diabase.

(1) Shows for each constituent number of grams altered rock required to contain the amount of that constituent originally present in 100 grams of fresh rock.

(2) Leith, C. K. and Mead, W. J., Metamorphic Geology, p. 21, 1915.

for the alumina. Magnesia, lime, soda, potash, and iron have all decreased relative to alumina, though iron has decreased only very slightly and within the limits of error of the analyses can be considered as increasing relative to alumina. If the graph of the other two pairs of analyses are considered it will be found that they have followed the same course as No. 1, with the exception of iron, which has decreased greatly in No. 2 but has increased slightly in No. 3. No. 1 corresponds most nearly to No. 3, especially in regard to the significant matter of the behavior of the iron.

The two analyses of basalt and diabase illustrate the difference in character of weathering of basic rocks under conditions of abundant oxygen and in environments of little or no free oxygen. In speaking of these two analyses, Leith and Mead say:[34]

> No marked difference between the two sets of analyses is observed except in the behavior of the iron. This is the characteristic difference found between rocks weathering at the surface under oxidizing conditions and those weathering below the surface where oxygen is absent or less abundant in the solutions. Iron, because of the insolubility of the ferric oxide, is extremely insoluble, in oxidizing solutions, but in the ferrous form, as carbonate or sulphate or salts of organic acids, it is comparatively soluble, and hence is easily dissolved and transported by reducing solutions.

If the average analyses of basalt and serpentine are approximately representative of conditions which produced the serpentine, it follows that the alteration was carried on under an oxidizing environment. There has been little solution of iron, the total amount has actually increased and the loss in respect to alumina has been very slight. It is believed that these factors are of significance in a consideration of the origin of the serpentine bodies and they will be considered again when the origin of serpentine is discussed.

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[34]Leith, C. K. and Mead, W. J., Metamorphic Geology, p. 22, 1915.

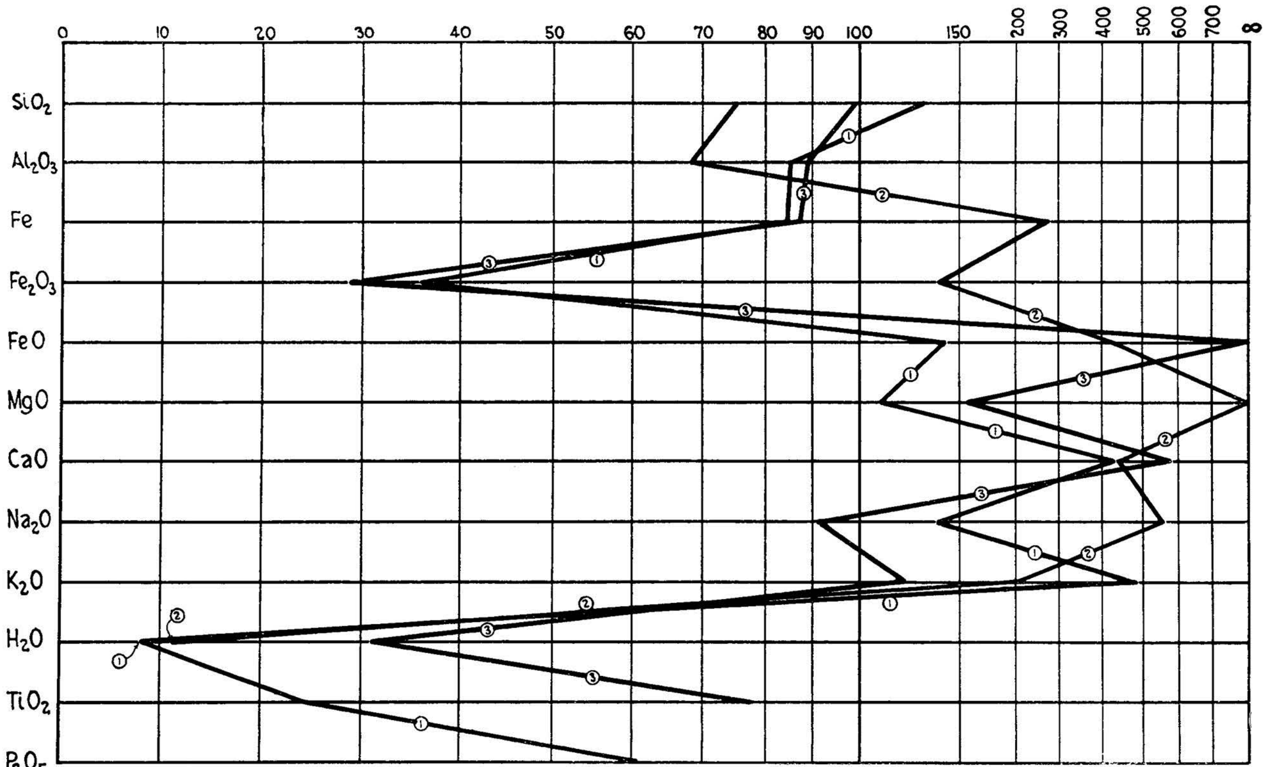

Fig. 20. Graph showing alteration curves of serpentine and basalt compared with alteration of diabase and basalt under similar and dissimilar conditions.

ORIGIN OF THE SERPENTINES

Serpentine of the Balcones Fault region has originated in a number of ways. The origin of certain occurrences seems readily explained, but others are in doubt and possibly cannot be explained at the present time. Some of the serpentine is a weathering material *in situ.* Part of it is of sedimentary origin constituting conglomerate and finer clastics. A third type, such as found in the oil fields and certain other localities is thought to represent the altered material of a volcanic extrusion on the floor of the Austin chalk sea.

Serpentine as a weathering residue.—A number of occurrences of serpentine as they exist today are simply the products of weathering of basaltic rocks. The serpentine at Knippa, Uvalde County, and at Pilot Knob in Travis County, in contact with basalt and at the locality three-fourths mile upstream from Black Waterhole, Uvalde County are the best examples. Small deposits of similar nature are to be expected near all of the bodies of basaltic rock and no doubt will be found when drilling, quarrying or other means exposes the flanks of such masses. Such serpentine is always in association with massive unaltered basalt occupying a position on the flanks of the igneous mass and connected with it by gradation from serpentine rock to partly serpentinized basalt and to unaltered basalt. In volume such masses of serpentine are usually a small part of that of the unaltered igneous rock and can be characterized as a weathering or alteration fringe.

Serpentine as found under these conditions is capable of undergoing further alteration. This is marked in the outer exposed surfaces by a change in color from green to greenish-yellow and finally to yellow and brown. Such changes are found in surface exposures and hence are not seen in the oil field serpentines. Material of this sort is found at Pilot Knob, Travis County, near St. Edward's College, at Austin, at Black Waterhole, in Uvalde County, at

Knippa, in Uvalde County, and in nearly all serpentine exposures.

The formation of serpentine rock from basic igneous rocks is the normal condition. This alteration has been described many times, but it may be of interest to repeat here the steps in the process since it is of so much importance. No better account exists than that by Leith and Mead[35] which follows:

> When basic igneous rocks are disintegrated without much chemical decomposition, the result is a dark green ferromagnesian sand. When chemical decomposition, transportation, and deposition take place, clays and iron oxides or iron carbonates, limestone and dolomite formations result. . . . The ultimate mineral products are clay, calcite, dolomite, iron oxide, and iron carbonate. As intermediate steps in the alteration of the basic feldspars to their end-products, there may be developed epidote, sericite, and more acid feldspars, in all cases with liberation of lime. From the augite there are developed hornblende and chlorite with separation of calcite. . . . Chlorite develops from the hornblende. Serpentine or talc may develop either from augite or horneblende. . . . Olivine alters to serpentine and magnetite. . . . The absence of free quartz in basic rocks, the smaller proportions of combined silica, and the correspondingly larger proportions of the bases, makes the basic rocks much more susceptible to attack by the agents of weathering, which are mainly acid in their nature. More energy is liberated by weathering of such rocks than of acid rocks. The weathering of basic rocks, therefore, proceeds more rapidly than that of acid rocks.

The serpentine found as a weathering residue near the Balcones region basalts is an intermediate product of the alteration of basalt. Certain facies of it represent more advanced phases of the alteration in which the process has gone nearly to completion. These are the yellow varieties and consist of clay, limonite, and calcite. The great mass of the material not only of the serpentine found in contact with basalt but the other forms also consists largely of serpentine and chlorite and is intermediate in character. Apparently the principal process involved in the alteration of

[35]Leith, C. K. and Mead, W. J., *op. cit.*, p. 20.

the rocks to form the intermediate serpentine is hydration. Addition of water is sufficient to form these minerals and the fact that the iron oxides, clay and carbonates are not present as integral parts of most specimens suggests that oxidation in the extreme sense has not operated.

The description of the formation of the serpentine material above will apply with equal force to the formation of serpentine of sedimentary nature and to the serpentine of the oil fields. The essential feature is the partial weathering of a basic igneous rock which results in an aggregate composed largely of the green minerals, serpentine and chlorite. The origin of the material is easily accounted for, its geologic occurrence is much more complex. For the serpentine in association with unaltered igneous rock the entire history of formation is plain. There has been normal weathering of a basaltic rock, leaving a zone which grades outward from unaltered basalt to serpentine and to weathered serpentine.

Sedimentary serpentine.—Under the term *sedimentary serpentine* is included all of these occurrences interbedded with sedimentary rocks or which show their sedimentary nature from structure or other features. Examples are found in Onion Creek north of Pilot Knob in Travis County, at Black Waterhole, in Uvalde County, and in many other localities. Many of the thin bodies of serpentine encountered in drilling are of this nature and the serpentine fragments scattered through the Austin chalk in Bexar County also are of this sort.

On Onion Creek generally in flanking positions to Pilot Knob many occurrences of serpentine have been noted and brief notes on these will be found in the list of serpentine occurrences. The material varies from a very fine-grained, dark green shale-like rock to material which is coarser and is almost conglomeratic in its features. In all cases these occurrences are in definite beds interbedded with Austin chalk. In some localities more than one bed occurs and there is evidence of local unconformities in connection with the beds.

Only two possibilities for the origin of the material can exist. Either the beds are true sedimentary rocks or they are ash or tuff beds deposited in the sea of Austin chalk times. There seems to be no very conclusive evidence on this question. Study of specimens of the material has failed to yield evidence of volcanic or ash structure and the specimens in general are not highly suggestive of volcanic origin, though some of the beds are sharply set off from the underlying chalk. If these beds are sedimentary, as they are thought to be, the source of the sediments was nearby and was a restricted one for they occur only over small areas. Apparently there is recorded in these beds the erosion of a basaltic hill or cone standing above the sea in Austin times. An alternative is that the beds represent ash deposits blown from a volcano in Austin times.

The deposit of serpentine at Black Waterhole represents an unusually interesting and instructive geologic phenomenon. Descriptions of the occurrence have already been given, and it is only necessary here to outline the evidence which is thought to prove the sedimentary origin of the rock. There is a definite sedimentary banding of the sort found in conglomerates, various aspects of this bedding being shown in figures in another part of the report. There is a sorting of materials characteristic of conglomerates and there is an interbedding with other materials, showing that the whole deposit is waterlaid. Included in the conglomeratic phase of the serpentine at this place are numerous cobbles of limestone, sandstone, and shale. These do not show the features of ejectmenta but of water-worn material. Many of the limestone fragments are Comanchean, showing that limestone of this age was available for sedimentation during early Austin or late Eagle Ford times.

The occurrence is believed to be sedimentary in all of its aspects except possibly one ledge 10 feet thick, which may be a sill of basalt altered to serpentine and which is of a more massive character than other parts of the deposit. In its larger features this deposit records the erosion of an igneous land mass (of very small size) close at hand because the deposit is essentially a basal conglomerate. Apparently hills or perhaps cones of basalt were common in the Cretaceous area of this region. Erosion produced near at hand such features as the Black Waterhole deposit and at greater distances such material as found in Onion Creek, Travis County. At still greater distances from the igneous mass under process of erosion little or no trace of the rock remains except as occasional pebbles, as in Bexar County.

To what extent, if any, volcanic activity contributed to deposits of the serpentine of the sort discussed here cannot be stated. No sure means of identifying and recognizing such material exists. It is not improbable that a part of the serpentine is of this nature, but deposits like the one at Black Waterhole and with less force, the ones in Onion Creek emphasize the fundamental sedimentary nature of the processes involved in their formation.

It is not possible to extend the evidence of the sedimentary serpentine exposed at the surface to the large buried masses of Lytton Springs and Thrall. Such occurrence represent a distinct problem and should not be confused with the bodies of serpentine which have just been discussed. It is probable that a certain number of bodies of serpentine encountered in the oil well drilling are of the sedimentary sort. In general any serpentine of no great thickness encountered in wells is likely to be of this sort. The finding of serpentine in a well is no indication of the discovery of a large body of the Lytton Springs type unless a notable thickness of the material is present.

Many examples of the sedimentary serpentine in addition to those discussed are known and others will no doubt be found in the future. Few exposures known yield such plain evidence of the type as those mentioned. Probably the discovery of serpentine interbedded with the normal sedimentary rocks is sufficient evidence to classify such occurrences and the occurrence of fossils in the rocks certainly removes them from the igneous class. In the absence of definite relations to the source, interbedded sedimentary rocks, fossils, and similar evidence, surface exposures of serpentine must defy classification at the present time for the material itself is not diagnostic.

Volcanic serpentine.—The third type of serpentine occurrences is that found in the two oil fields, Thrall and Lytton Springs, and encountered also in wells in Bastrop, Caldwell, Travis, and Medina counties. In physical aspects, in size and shape, this type differs from the purely sedimentary or weathering serpentines. In the case of both Thrall and Lytton Springs bodies of serpentine of large size have been demonstrated, their shape being that of a low cone with minor surface irregularities. Such masses of serpentine are essentially different in their geologic setting to the fragmentary and minor occurrences found at the surface, even though the rock material itself is the same.

A number of modes of origin of the oil field serpentines have been suggested. Among the theories presented, the following are included: (a) The serpentine mass is a sedimentary rock; (b) the serpentine represents a volcanic cone extruded in the Austin sea in which case the materials are altered tuff, ejecta and flows; (c) the serpentine bodies have resulted from the alteration of both intrusive and extrusive igneous rocks localized at a volcano. That the general mass of a body of serpentine, as found at Thrall and Lytton Springs, is due to sedimentary processes is inconceivable. The shape and the size of the occurrences is such as to prohibit any such origin. It is true, however, that the serpentine bodies have been in the zone of sedimentation because specimens from the upper parts of both Thrall and Lytton Springs show sedimentary characters and contain minute fossils. No matter what previous history was involved there was a period in the history of such bodies when the entire mass was beneath water and was in a sedimentary environment.

It is likewise improbable that the oil field bodies of serpentine as units were intrusive bodies such as stock, plugs or laccoliths. This suggestion was made by Baker on the basis of the complete crystallinity of specimens from Thrall, but will not hold in the face of other evidence. If the bodies were intrusive then cover must have been removed to permit erosion and mingling with sedimentary materials as now found in the upper parts. To account for this an erosion interval and unconformity of considerable magnitude would be necessary and no such event is recorded in the rocks of the region. Furthermore, had the serpentine masses been formed as intrusives the characteristic recrystallization of the surrounding limestone would have occurred and no such feature has been found. In addition the alteration of a large body of massive intrusive rock into serpentine under such conditions presents almost insurmountable difficulties. Finally when the textures of the rocks are considered it cannot be conceived that the crystallinity of the original rock is more suggestive. Basaltic magmas are notably fluid and it is not uncommon for basaltic flows to be completely crystalline. The rocks from which the serpentines were derived were very basic and the fact that they crystallized does not warrant an assumption that such a condition was due to cooling at depth beneath a cover.

It is entirely possible and indeed probable that sills of originally intrusive rock have been found in the wells of Thrall, Lytton Springs and other places. It seems likely that some of the isolated masses at Lytton Springs were of this sort and that the well near Pilot Knob also encountered similar material.

There remain the theories which account for the origin of the serpentine deposits through extrusive igneous activity and which classify the serpentine as an altered extrusive rock. Such theories are modified, as by Collingwood and Rettger, to include an indefinite amount of intrusive material but in general the idea of an extrusive mass as originally postulated by Udden and Bybee is the fundamental premise of the theories. When the shapes of the serpentine bodies and their degree of alteration are considered there is no escape from the conclusion that these deposits were formed by igneous activity and that the rocks were placed so that thorough alteration was readily accomplished. The extrusions of basaltic material is the only means by which this could be brought about because the exposure of igneous material at the surface, either above or below the surface of the sea, is the only means by which the alteration could be effected.

There has been a tendency among geologists to compare the serpentine bodies of Pilot Knob in Travis County and to speak of the former as "serpentine plugs." Pilot Knob, as has been shown in this report, is an intrusive plug or stock probably of Tertiary age. It has been exposed to weathering for a long period of time and still consists of massive unaltered basalt. The serpentine bodies, on the other hand, could have been exposed only a relatively short time and are thoroughly altered. To compare them to Pilot Knob is to start with an erroneous assumption and to cause confusion in any discussion of their origin.

It is impossible to state exactly the history of the serpentine bodies. They are known only through samples from wells, their relations to the surrounding rocks known in only a very small part of the occurrences and no exactly similar bodies, even in miniature, are known at the surface. Therefore, any statement which goes farther than to point out that the deposits were extrusive must be speculative. It seems fairly certain that the original rocks were extrusive, but whether extruded on the sea floor or on land, whether tuffaceous or entirely massive, or whether the eruptions were quiet or explosive, cannot be determined. Certain inferences seem most reasonable but there is at present no proof for more positive statements.

Collingwood and Rettger have stated that the conflicting evidence on hand leads them to conclude that the Lytton Springs body is both intrusive and extrusive. This can hardly be the case for this or any other serpentine mass, for if the serpentine to an appreciable extent was of intrusive origin, unaltered rock would remain. It is conceded that minor sills or dikes might be present, but judging from the exposed basalts in Texas and other igneous regions, the alteration could not be complete in the case of an igneous mass any essential part of which was intrusive.

The degree and kind of alteration of the serpentine is one of the most significant features present and suggests if indeed it does not prove the extrusive origin of the material. It is even reasonable to suppose that the complete alteration present argues a tuffaceous character in addition to that of extrusion. Basaltic dikes in the eastern United States exposed at the surface since late Cretaceous times invariably yield some unaltered rock. How great then is the difference in alteration between such rocks and the serpentine? If the serpentine rocks were deposited largely as tuffs then alteration would be most easily accounted for, since this type of deposit offers the easiest passage to the agents of alteration. Pirsson[36] has discussed this point and is quoted as follows:

> The weathering of tuffs is comparatively easy when they are loose and uncompacted, owing to the ready access of air and moisture and also to the relatively large surface areas exposed in such fine grains. Hence the feldspathic tuffs are readily kaolinized and converted into soft earthy masses. . . . In basaltic tuffs, as in the so-called palagomites, the alteration adds to the formation of secondary silica, zeolites, chloritic minerals, carbonates, and limonite. The cement between the ash particles is first attacked and as the alteration proceeds with the particles themselves, the original structure may be more and more obscured until it is finally lost. . . .

It is thought unwarranted to conclude that all of the material of the serpentine was tuff, the microscopic evidence not being conclusive. Since the original rocks as a whole were extrusive it is probable that a certain part were tuffaceous and that these tuffaceous materials, along with the more massive ones, afforded the agents of alteration ready access so that the rocks were completely changed. How much material was tuffaceous cannot be stated, indeed it cannot be proved that any part was of this character, but

[36]Pirsson, L. V., The Microscopic Character of Volcanic Tuffs—A Study for Students. Am. Jour. Sci. (4), 40, pp. 204–207, 1915.

whatever the nature of the products of extrusion, the conditions were such that alteration proceeded more rapidly than is the case usually with solid basaltic rocks. Furthermore, the analyses available suggest that the alteration was brought about in the zone of weathering.

Udden and Bybee presented evidence suggesting that the Thrall serpentine was extruded on the sea floor, calling attention to differences in the overlying rocks which suggested current action. The serpentine bodies of both Thrall and Lytton Springs apparently were near sea level and at times beneath it. Many specimens from both localities show distinctly sedimentary aspects and from the upper parts of both masses foraminifera were secured. In addition a great number of deposits of sedimentary serpentine are known and have already been mentioned. Apparently the concluding event in the history of each occurrence was a matter of sedimentation in which the upper part was reworked and sorted by wave action. How much of the history of the serpentine bodies is really sedimentary rather than igneous cannot be told, but it would not be surprising to find that sedimentary processes have played a far greater part than hitherto believed. Evidences of local unconformities in Austin times are not lacking, as shown in Onion Creek, Travis County, and it is readily conceivable that the serpentine masses during their alteration may have undergone depression and elevation a number of times in reference to sea level. Furthermore, it is probably that the extrusive action was intermittent and that extrusive masses slightly above sea level were reduced to sea level and again built up by fresh supplies of volcanic material. Such conditions would aid rather than handicap alteration.

Recent geophysical investigations of the serpentine bodies not yet published are reported as failing to reveal dense rock underlying the serpentine deposits. This is evidence of the extent of alteration and destroys the "plug" theory so commonly held. The extrusions must have come to the surface through relatively small and insignificant passages, a condition to be expected when comparison is made with known extrusions.

If the explanation of the serpentine presented here is correct, the sedimentary serpentine masses previously mentioned are easily understood. Extrusive bodies of basalt whether above the surface of the ocean or near it furnished the source of the material for such deposits. Near the source the sediments were coarse and poorly sorted, farther away they were finer. These conditions actually prevail and each sedimentary serpentine mass can be regarded as a part of the formation in which it occurs and as an indication of a source rock mass at no great distance. Incidentally, the igneous history of the Balcones region is thus augmented to include a period of basaltic extrusion in Cretaceous times.

ECONOMIC CONSIDERATIONS

RELATION OF SERPENTINE TO ACCUMULATION OF PETROLEUM

The relation of the serpentine masses to the accumulation of petroleum is a matter of importance. The statements of Udden and Bybee, and of Bybee and Short in reports previously cited, give information on the Thrall and Lytton Springs fields. The masses of serpentine lying above the Austin chalk are supposed to have derived their oil from the Taylor marls, the oil having migrated into the highly porous serpentine. Within productive serpentine masses the oil content was largely confined to areas of greater porosity and these were generally found near the central and upper parts of such masses. Judging from the two productive fields of this type, the oil accumulations are largely local.

Since the discovery of Lytton Springs three noteworthy occurrences of serpentine have been found in Bastrop, Caldwell and Travis counties. Of these, the one in Caldwell County[36a] showed small amounts of oil, but the wells failed to produce in commercial amounts. The serpentine of the remaining two localities was dry and no attempts have been

[36a]As stated earlier in the report the serpentine near Dale, in Caldwell County, has been found to contain oil and a new field is being developed at the present time.

made to explore further, though considerable bodies of the serpentine were found. It is commonly stated that the material found was not sufficiently porous to contain oil.

If the experience gained in the producing fields and the non-producing localities is to be relied upon, it seems certain that the fundamental character of a serpentine mass permitting petroleum accumulation is high porosity. Such conditions cannot be predicted and can only be learned by actual drilling experience. Presumably any large serpentine mass located in the Taylor marl would be oil-bearing if sufficiently porous.

The origin of the high porosity in parts of the Lytton Springs field has been discussed by Collingwood and Rettger. They state that the greatest porosity would be expected near the central part of the dome. It is possible that the high porosity of certain parts of the serpentine masses is due to the presence or absence of sedimentary materials, and to the kind of sedimentary textures present. If the mass of serpentine is a purely volcanic body the degree of porosity should be fairly uniform and high. The covering of any part of such a mass by fine tuff-like sediment will, as pointed out by Collingwood and Rettger, lower the porosity, but, on the other hand, if the upper flanks of such a mass are covered by a basal conglomerate akin to that at Black Waterhole, the porosity would not be greatly changed. A serpentine mass completely covered with fine sediment would be more or less effectively sealed, lowering the porosity and resulting in a poor reservoir rock for oil. The conditions of any given mass of serpentine would depend entirely on its individual history and cannot be predicted.

Drilling done to date seems to show that oil cannot be expected in the relatively thin bed of serpentine such as have been encountered in some walls. Probably these are of too limited an extent to act as reservoirs, though it is true some are highly porous. It is possible that such are so interbedded with normal sedimentary rocks that an effective seal is formed.

It is likewise apparent that drilling is not justified by the occurrence at the surface of an exposure of serpentine. If the exposure is a sedimentary facies it is at best only a small body of the material. On the other hand, if the top of a larger mass is exposed, the fact that the serpentine is now at the surface prohibits any chance for an oil accumulation. Only large masses of the material concealed at depth, located in the Taylor marl, and of a proper porosity, are thought favorable.

The detection of such buried masses of serpentine is a matter of great difficulty in the majority of cases. As has been shown by Bybee and Short, the presence of the Lytton Springs mass was indicated by surface geologic conditions. The same is true to a limited degree of Thrall, and it is said that the serpentine mass in Travis County could be detected in the surface geology. A search for similar surface indications may possibly reveal other occurrences, but it is probable that serpentine bodies exist showing no surface indication. The most likely means of finding the buried serpentine bodies seems to be based on geophysics. Results of work done up to the present on proved fields are reported to be negative and areas reported favorably were found through drilling to be barren of serpentine. Nevertheless, the possibilities of this method have not been exhausted because the entire procedure is still relatively new. The serpentine itself is so unusual a rock that the application of some geophysical method may possibly be used to detect it, and the development of a technique along this line may bring success in locating serpentine.

The prospect for the discovery of new serpentine oil fields cannot be regarded as encouraging. In the first place, the very nature of the occurrences limits the number of such fields available. If, as is believed, each larger mass represents a locus of volcanic activity at the close of the Austin, the existence of oil fields of this type will be conditioned by the number of volcanic outbreaks in the region. There is no reason to suppose that these were numerous, particularly in the northern part of the Balcones region since extensive work by the oil companies has failed to find evidence of them. If the Tertiary igneous activity is any index of the earlier Cretaceous eruptions it can be seen that the northern part of the igneous field would not be likely to contain many such occurrences.

There is no evidence showing that the Tertiary activity corresponded to that of Cretaceous times, but it would not be surprising if this is the case. If the correspondence exists in the activity of the two periods, the southwestern part of the Balcones region, centered in Uvalde County, offers the best opportunity for the discovery of new fields of this sort. The Uvalde County district is least drilled of the counties in the Balcones regions and for this reason also represents the best chance for new serpentine finds. It is less explored and therefore more likely to contain undiscovered serpentine masses. Presumably the presence of great numbers of the Tertiary igneous rocks in the Uvalde district has discouraged drilling and exploration. If the conclusions reached later in this report are valid, these igneous rocks will have little disadvantageous effect on the accumulation of oil. The outlook for new serpentine fields is not encouraging also because there is no assurance that a serpentine mass when discovered will contain oil. The question of porosity seems to be all-important and since this factor varies so greatly in the serpentine deposits, so will their productivity vary. Up to the present time only two of seven serpentine masses believed to be of the Lytton Springs type have produced oil. The discovery of Thrall and Lytton Springs may perhaps be regarded as fortunate accidents. If the proportion of producers holds for new bodies of serpentine, the discovery of a new field of this type will probably be made only after considerable drilling. It is believed that such fields may be found but under present conditions, no sure method of finding other than by drilling is known.

RELATION OF MASSIVE IGNEOUS ROCKS TO ACCUMULATION OF PETROLEUM

This section of the report deals only with the possibilities for oil in association with massive unaltered igneous rocks, the discussion relating to the unaltered igneous rocks and surrounding sedimentaries such as found at Pilot Knob, Knippa, Black Waterhole, and elsewhere along the Balcones Fault line. Furthermore, this discussion is limited to that narrow belt of country in which the igneous rocks actually outcrop at the surface and is not concerned with districts under which igneous rocks may be thought to be buried. The surface sedimentary rocks are generally upper Cretaceous and to a smaller extent lower Cretaceous formations. The southeasternmost part of the district is in places covered with lower Tertiary formations and these, in general, limit the zone or belt under discussion, which comprises a comparatively small area in which conditions are somewhat specialized.

Since oil has actually been obtained in Mexico in association with igneous rocks, a consideration of the conditions prevailing there will be of importance in the present discussion. Through the writings of De Golyer, Garfias, Huntley, and others the structural and stratigraphic conditions in the Mexican fields are well shown.[37].

Their work has been done in sufficient detail to furnish a basis for comparison between the two districts. A review of the work shows certain significant similarities and dissimilarities between the two districts. The stratigraphy of the Mexican fields is somewhat the same as that of the Texas districts. Lower Cretaceous, upper Cretaceous, and Tertiary rocks are present in both regions, though in the Texas localities the Tertiary formations for the most part

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[37]De Golyer, E., The Furbero Oil Field, Mexico. A. I. M. E., Trans. 52, pp. 268–280, 1915.

The Effect of Igneous Intrusions of the Accumulation of Oil in the Tampico Tuxpam Region, Mexico. Econ. Geol., Vol. 10., pp. 651–662, 1915.

Garfias, V. R. and Hawley, J. N., Funnel and Anticlinial-ring Structure Associated with Igneous Intrusions in the Mexican Oil Felds. A. I. M. E. Bull. 128, pp. 1147–1159, 1917.

Garfias, V. R., The Oil Regions of Northeastern Mexico. Econ. Geol., Vol. 10, pp. 195–224, 1915.

The Effect of the Igneous Intrusions on the Accumulation of Oil in Northeastern Mexico. Jour. Geol., Vol. 20, pp. 666–672, 1912.

Huntley, L. G., The Mexican Oil Fields, A. I. M. E. Trans. 52, pp. 281–321, 1915.

have been removed by erosion. Oil is obtained in the Mexican fields from horizons in the upper Cretaceous and the Tertiary. There is no close similarity in the stratigraphy of the two regions, but a general correspondence exists which includes rocks of equivalent ages, though the correlation of horizons has not been carried out in detail.

The igneous rocks in the Mexican fields are composed of dikes, sills, laccoliths, and plugs of basalt or closely related types. These were intruded in late Tertiary times and reached stratigraphic levels far above those invaded by the igneous rocks of Texas which, as has already been shown, cannot be proved to younger than early Tertiary. Notable seepages of oil are found in connection with the Mexican igneous rocks occurring along the flanks of outcropping igneous bodies in great abundance and are also found in locations not related to surface occurrences of the igneous rocks. In the latter case, buried igneous masses are hypothecated by many of the writers.

The later writers on the Mexican fields agree fairly closely as to the rôle of the igneous bodies in the accumulation of the oil. It seems to be established that the intrusion of igneous sills, dikes, plugs or laccoliths modified structure to only a very slight extent. The regional anticlinal structures with which the oil is associated are held to be earlier than the igneous activity and many of the intrusions are located not at the crests of structures but along the flanks or even in synclinal positions. A well pronounced alignment of the igneous masses suggests a control by fissures or other lines of weakness in the sedimentary rocks.

No attempt will be made here to discuss in detail the presence or absence of oil-bearing formations in the Texas region in which the igneous masses occur. Conditions are generally those which prevail throughout the southwestern part of the state. Although little or no attempt has been made to test the formations near igneous bodies, extensive drilling has been done in relation to other types of structure.

The formations which might be expected to produce oil, generally, in the region would also be the favored formations in any structure associated with igneous rocks. Such formations exist and would, of course, be matters for investigation in connection with any individual igneous-sedimentary structure.

In the Texas igneous localities it is believed that the structural conditions have been modified locally to a considerable extent by the force of intrusions. The Black Waterhole occurrence is the most noteworthy example. At that place there is a pronounced anticlinal structure adjacent to an intrusion, which although only partially exposed, is revealed so well that little doubt can exist as to its occurrence. That the structure present is due to intrusion is shown by a second structural rearrangement adjacent to a neighboring igneous body one-half mile upstream. Furthermore, at Black Waterhole there is evidence which suggests the anticlinal ring structure of Garfias, for near the contact of basalt and sedimentary rock a dip toward the basalt is observed; a similar structure is seen in connection with the igneous mass north of Cline, Uvalde County, where the Austin beds dip in toward the igneous rocks near the contact. The amount of closure of the structure at Black Waterhole has not been determined. It is thought, however, to bring to the surface the Eagle Ford beds, while upstream and on the flanks of the structure the Austin chalk is exposed. While the details of structure at Black Waterhole have not been determined, the very evident anticlinal relations suggests the possibility of an oil accumulation.

At Knippa, Uvalde County, there is also evidence of anticlinal structure of the sedimentary rocks flanking a basalt plug. Here no pronounced anticline as at Black Waterhole is seen, but the beds of the Austin chalk are seen to dip away from the northern flank of the plug. Evidences of anticlinal structure are seen in connection with many of the plugs where the surrounding sedimentary rocks are exposed. Many of the plugs, however, are flanked with masses of débris so that the structural relations cannot be determined.

It is probable that conditions are much the same in all of the igneous occurrences.

At Green Mountain, in Uvalde County, erosion has bared the igneous mass deeper than in other occurrences. As far as could be told there was practically no rearrangement of the beds of the Edwards formation which enclose the igneous mass. Since the occurrence is the most deeply eroded of those known, it may be that it furnishes an indication of conditions at depth. If so, no encouragement for oil and gas accumulation can be found, since there is a virtual absence of anticlinal structure. In practically every instance where anticlinal structure is known in connection with an igneous body other igneous masses occur nearby, and in some localities several plugs are found in a single square mile. Obviously, if all of these bodies of igneous rock are united a few hundred feet beneath the surface very little chance for oil exists. The great abundance of igneous masses in the Uvalde district has probably discouraged drilling. It is probable that the igneous rocks of Uvalde County and other counties along the Balcones Fault are practically distinct bodies united only at great depths. It is thought that the faulting with its developed fissures and lines of weakness has localized the igneous action in a linear belt. This belt of weakness is shown to extend from southeastern Arkansas to near Del Rio. Igneous rocks along this belt are undoubtedly related, showing many clan characteristics. Yet it is absolutely certain that along much of this line no magma reservoir, now frozen, exists at any slight depth. The extensive drilling along the Balcones Fault has failed to encounter such a mass. Furthermore, the basaltic nature of the rocks suggests that the common reservoir furnishing them was deeply buried. In the Uvalde district considerable differentiation has occurred. This is of a sort that indicates such action at depth and not locally a few hundred feet beneath the surface. While no positive statement can be made and while any conclusion is almost entirely speculative, there is no reason to believe that the abundance of igneous bodies in parts of the belt considered here is so great as to destroy the chance for oil accumulation. This would be true even thought the igneous activity occurred after oil accumulation which may not be the case.

No doubt investigations with the siesmograph or other geophysical apparatus would yield data from which the shape of these igneous masses could be deduced. Such information would not only be of economic value but would also be of great interest from a scientific standpoint.

The degree of metamorphism produced by the igneous rocks would affect oil accumulation to produce greater space for oil migration. It will be remembered that in the Mexican districts this condition was found. There is no evidence of this condition in the area covered by this report, since no seeps occur and since few exposures showing metamorphic effects have been found. It has been suggested from time to time that the heat action of the igneous rock would destroy oil accumulated so that areas of extensive intrusion would be unfavorable for oil on this account. Probably oil would behave very much as coal in this respect and if so the effect of the intrusions would be negligible. Eby[38] has shown that basaltic intrusions penetrating coal vertically affect it only for a few inches from the contact Intrusions horizontally beneath coal have a much greater effect. In general metamorphism from basaltic rock is slight and in instances known here consists in a recrystallization of limestone immediately in contact with the igneous rock.

From the discussion it should be obvious that no highly optimistic opinion can be held of the possibilities for oil in connection with structures surrounding igneous masses. The structures seen in favorable locations appear to have some possibilities. Against the bare fact of pronounced anticlinal structure there stands the conditions of doubtful continuation in depth of the structure, unknown conditions

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[38]Eby, J. B., Contact Metamorphism of Some Colorado Coals. Trans. A. I. M. E., No. 1414, I, 1925.

of oil-bearing horizons and a vast ignorance as to the conditions of the igneous rocks below the stratigraphic level of the Edwards limestone. While the structures would perhaps appear tempting, it may be that they are found only in the uppermost horizons intruded and are not present beneath, as, indeed, is suggested by the Green Mountain body. The mere abundance of igneous material would not seem to be of great importance since many isolated occurrences are known, nor is the effect of metamorphism of oil to be greatly feared. The whole problem seems to be that of continuation in depth of structures, size of structures and presence of oil-bearing rocks.

Against adverse factors which will probably prohibit drilling stands the fact, that should structures mentioned here be found to produce, a large prospective territory would be opened. Should a single structure alongside an igneous plug furnish oil, many other similar structures could doubtless be found. Such conditions would perhaps warrant at some date a test of the oil possibilities, though under prevailing conditions the drilling of such structures can only be regarded as exceedingly speculative and risky.

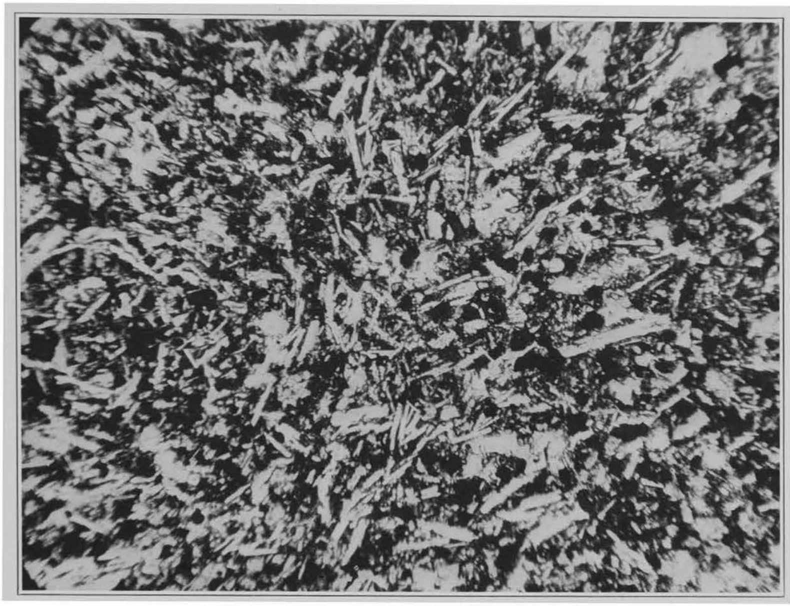

Fig. 1. Olivine-basalt from 8 miles south of Cline, Uvalde County. The light slender crystals are labradorite, medium gray is augite, and black, magnetite. Plane polarized light × 46.

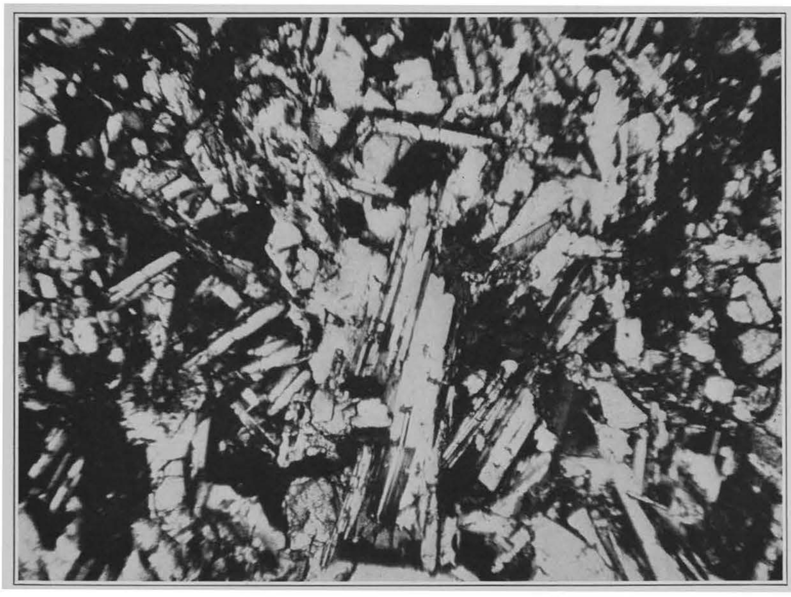

Fig. 2. Olivine-basalt from Turkey Mountain, Kinney County, The section shows labradorite in prominent laths, black magnetite gains, and gray augite. The magnification is the same as Fig. 1 and serves to show the difference in texture among the olivine-basalts. Plane polarized light crossed nicols × 46.

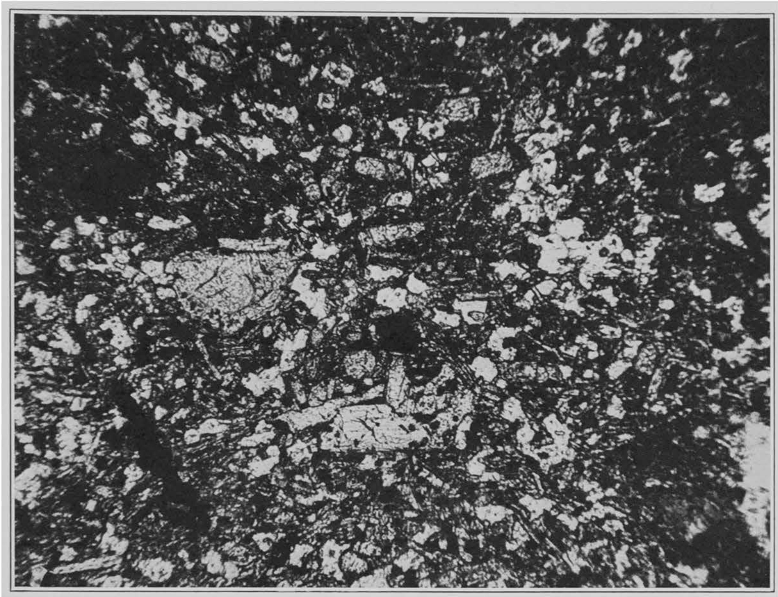

Fig. 1. Nephelite-basalt from Yucca Siding, Uvalde County. The areas of the groundmass are nephelite with subhedral development. The section also shows augite, olivine, and magnetite. Plane polarized light × 82.

Fig. 2. Nephelite basalt from Round Mountain, Uvalde County. Nephelite occurs in this rock as a groundmas paste and not in small distinct grains as in Fig. 1. The light gray crystals with rough surface are olivine, dark gray prismatic crystals are augite, the white areas are nephelite, and the black grains are magnetite. Plane polarized light × 82.

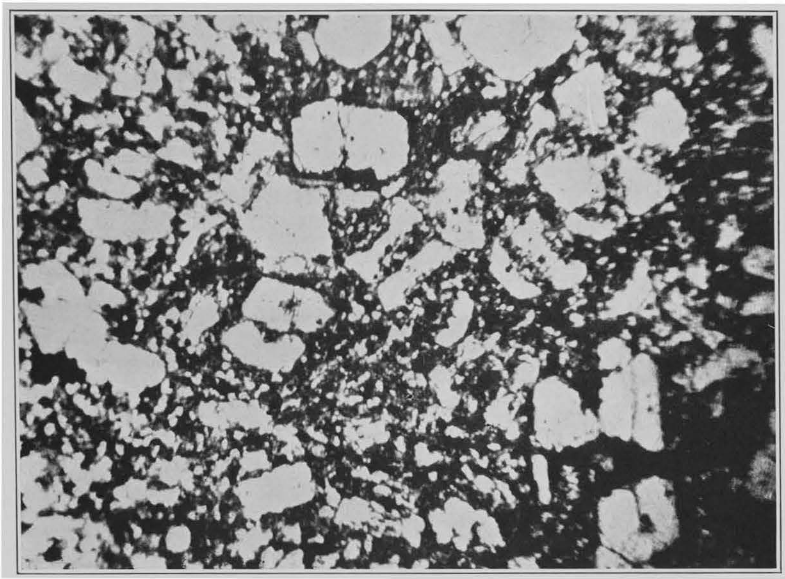

Fig. 1. Nephelite-melilite-basalt from Tom Nunn's Ranch, Uvalde County. The light colored areas are olivine and melilite, darker areas are augite and magnetite. Note cruciform twin of melilite in upper right corner. Plane polarized light × 26.

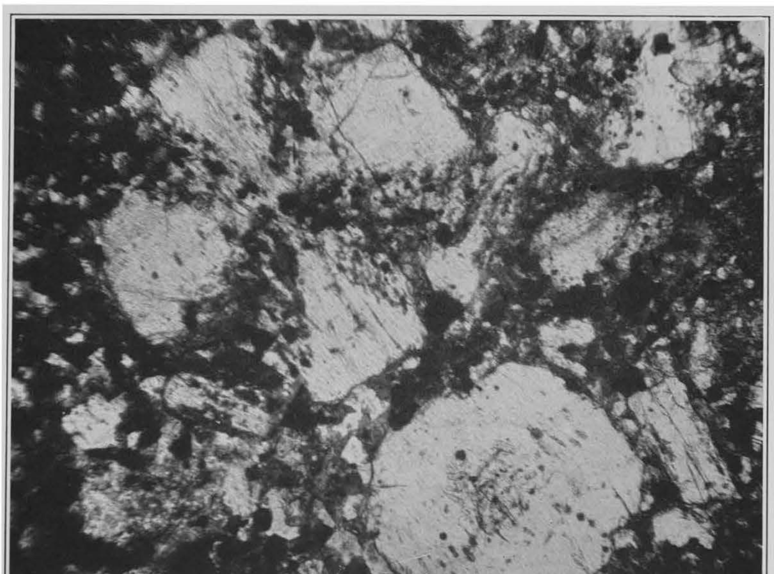

Fig. 2. Nephelite-melilite-basalt from Tom Nunn's Hill, Uvalde County, showing cruciform twin and basal section of melilite. Plane polarized light × 65.

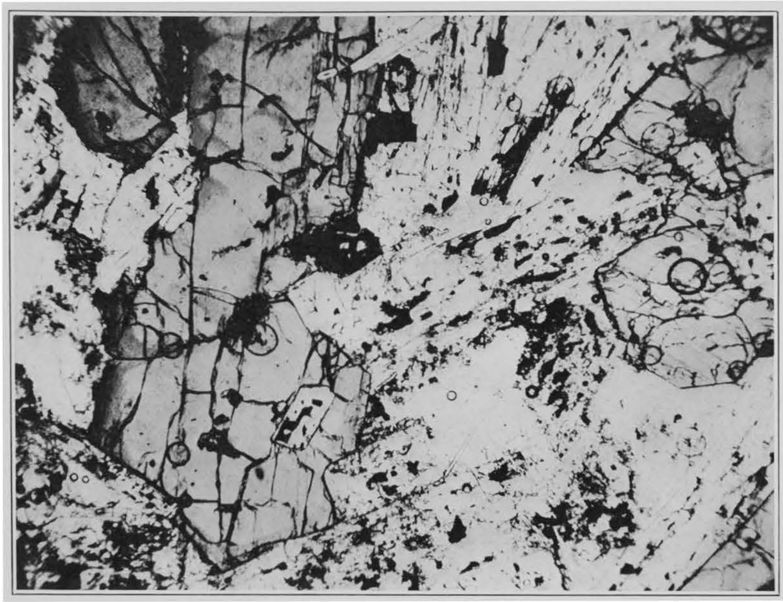

Fig. 1. Gabbro from Green Mountain, Uvalde County. The light part of the secion is plagioclase in prismatic crystals. The large gray crystal near the center of the field is violet augite, including and moulded around feldspar. In the lower central part of the section are minute needles of apatite. Black areas are magnetite. Plane polarized light × 26.

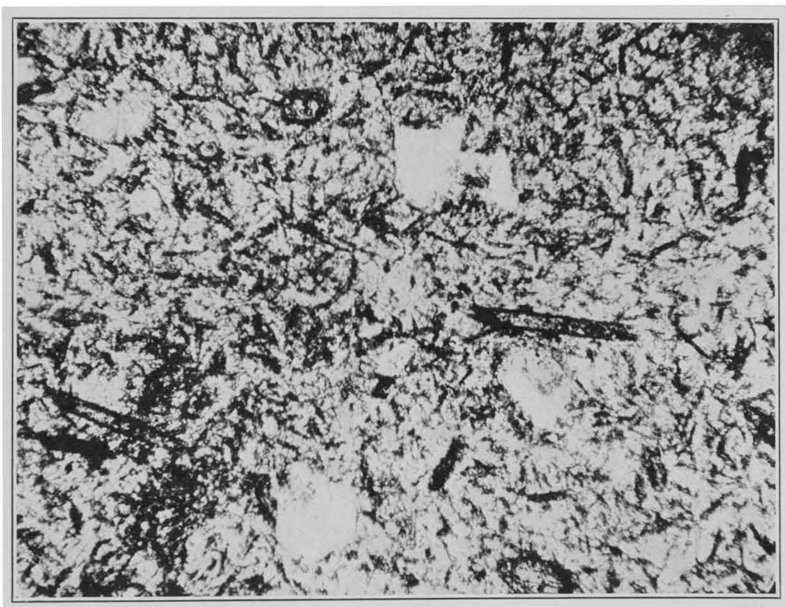

Fig. 2. Phonolite from Ange Siding, Uvalde County. The figure shows needles of aegirite-augite, phenocrysts of colorless nephelite, and a groundmass of alkali feldspar. Plane polarized light × 82.

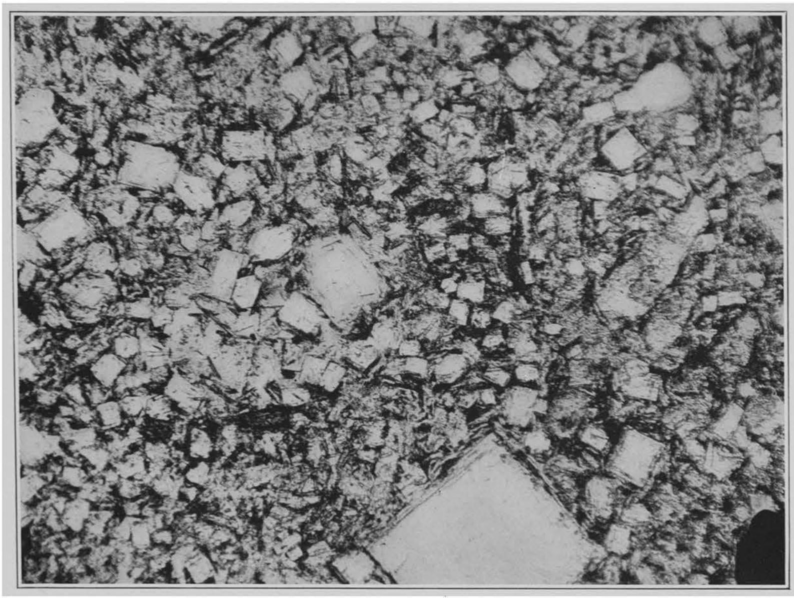

Fig. 1. Nephelinite from 2 miles south of Black Waterhole, Uvalde County. Essentially a two-mineral rock composed of euhedral nephelite showing both prismatic and basal sections and aegirite-augite in slender darker crystals. Plane polarized light $\times$ 82.

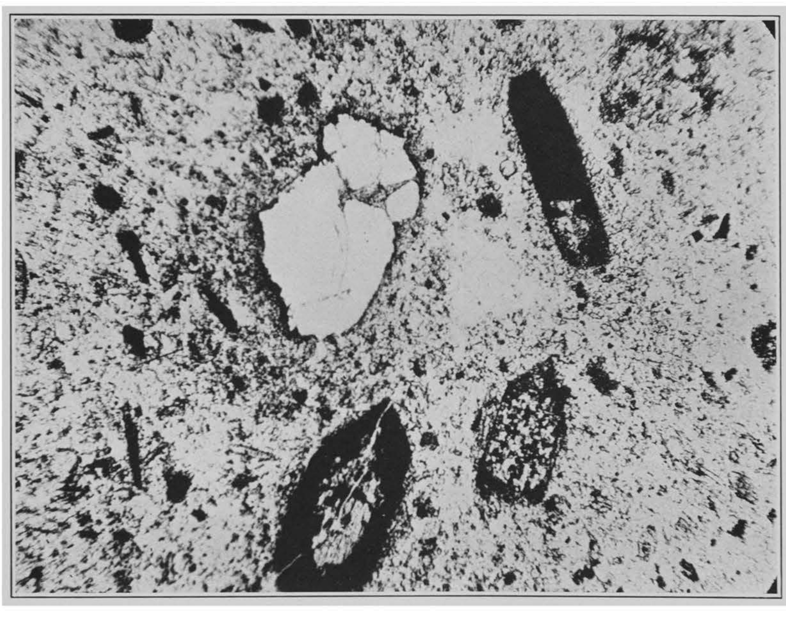

Fig. 2. Uvalde phonolite from Mount Inge, Uvalde County. The light-colored irregular area in center of section is olivine. The black crystal with gray interior at bottom is hornblende resorbed and recrystallized as magnetite and pyroxene. Only the central part is still hornblende. Black areas are magnetite mostly resulting from recrystallization of hornblende. The groundmass is very fine grained and feldspathic. Plane polarized light $\times$ 26.

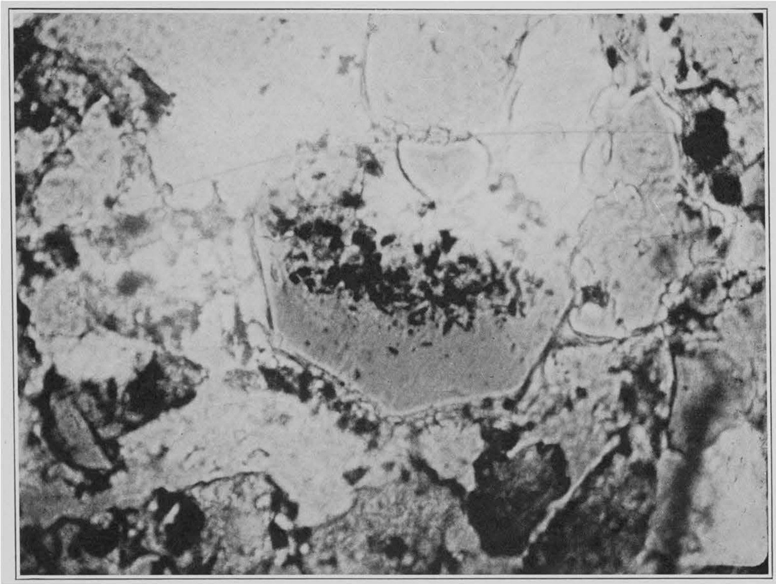

Fig. 1. Photomicrograph of thin section of serpentine from Thrall, Williamson County. The euhedral crystal in center of field is serpentine pseudomorph after melilite, the basal section being shown.

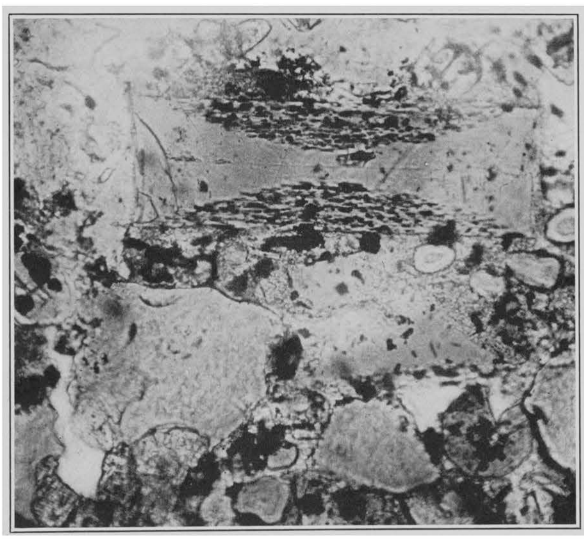

Fig. 2. Same as Fig. 1, but shows a prismatic section of serpentine pseudomorph after melilite. Comparison with Fig. 2, Pl. IV, will show the similarity in crystal outline between the original mineral and the pseudomorphs shown in this figure and in Fig. 1.

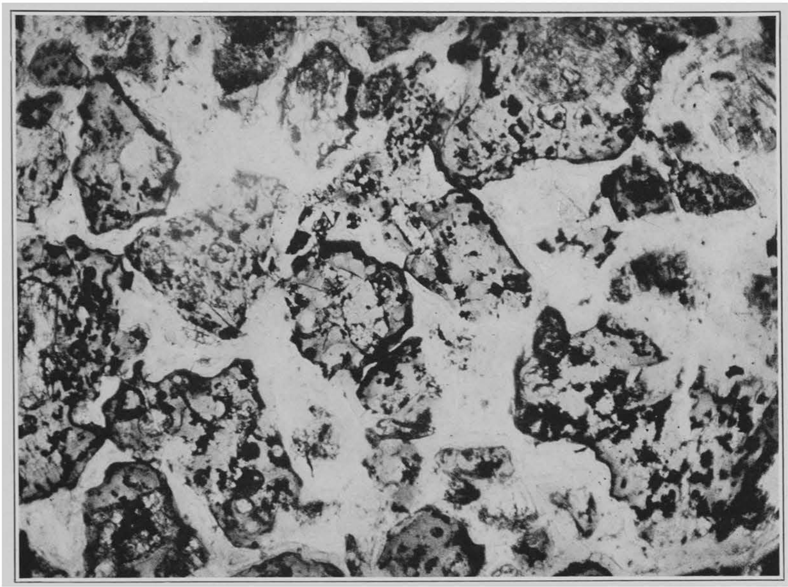

Fig. 1. Photomicrograph of thin section of serpentine from Thrall. The dark gray areas are dark green serpentine masses with pseudomorphs and spherulites of serpentine. The lighter material is light green serpentine comprising the ground mass. This texture is typical of much of the serpentine rock.

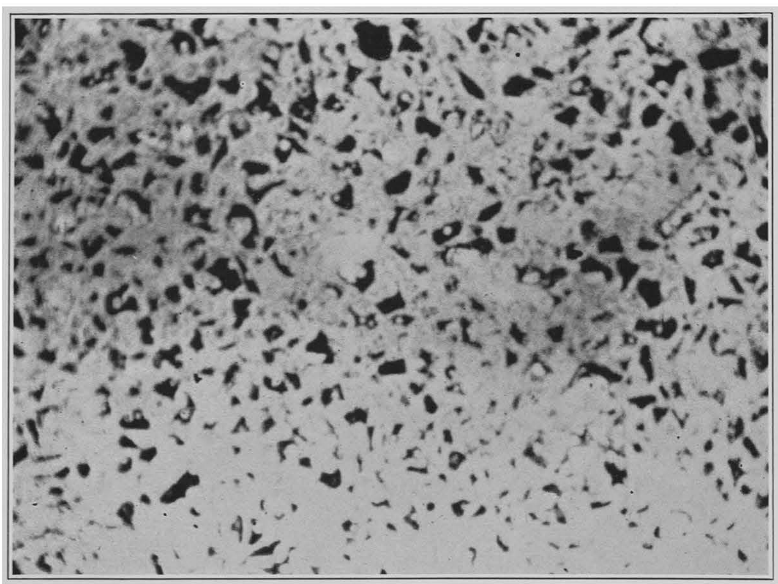

Fig. 2. Tuff-like serpentine from Thrall. The black areas are dense material, the shapes of which suggest pyroclastics. The lighter material is green serpentine.

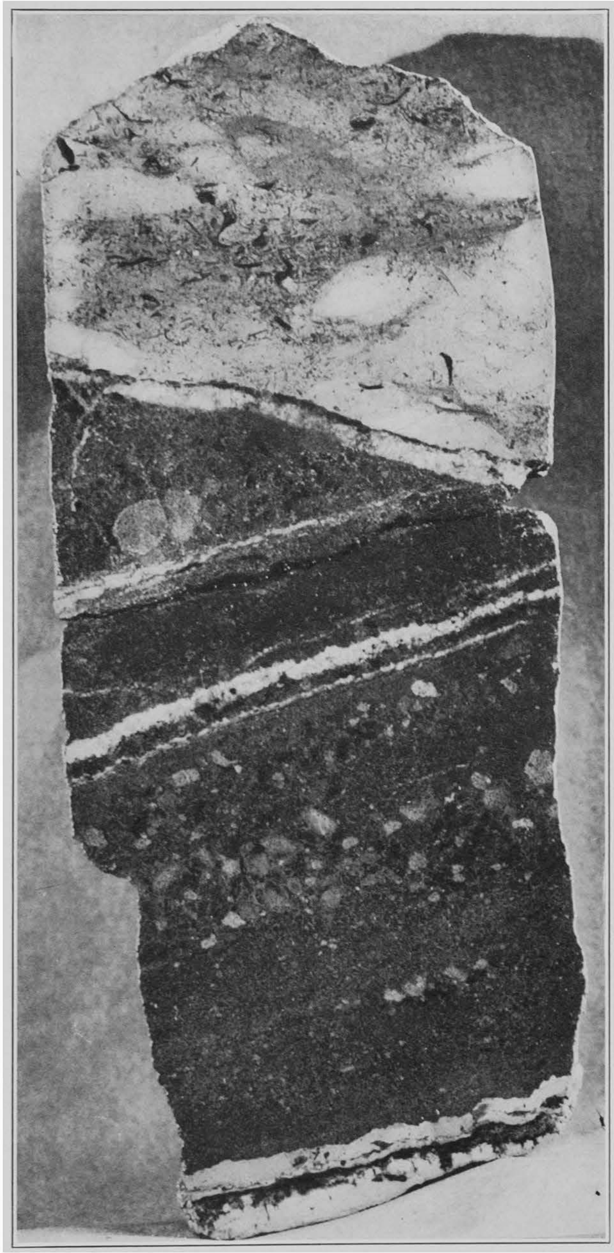

Fig. 1. Photograph of core from Gulf Production Company, No. 1 Brewer, depth 1190–1191, Lytton Springs. Upper part of core is Austin Chalk unmetamorphosed and containing fossils. Lower part fragmental serpentine veined with calcite. Extreme lower part chalk. Serpentine is believed to be sedimentary and the chalk deposited on it unconformably. Note the vein between chalk and serpentine and the relation of veins in the serpentine to the bedding of the serpentine. Slightly reduced.

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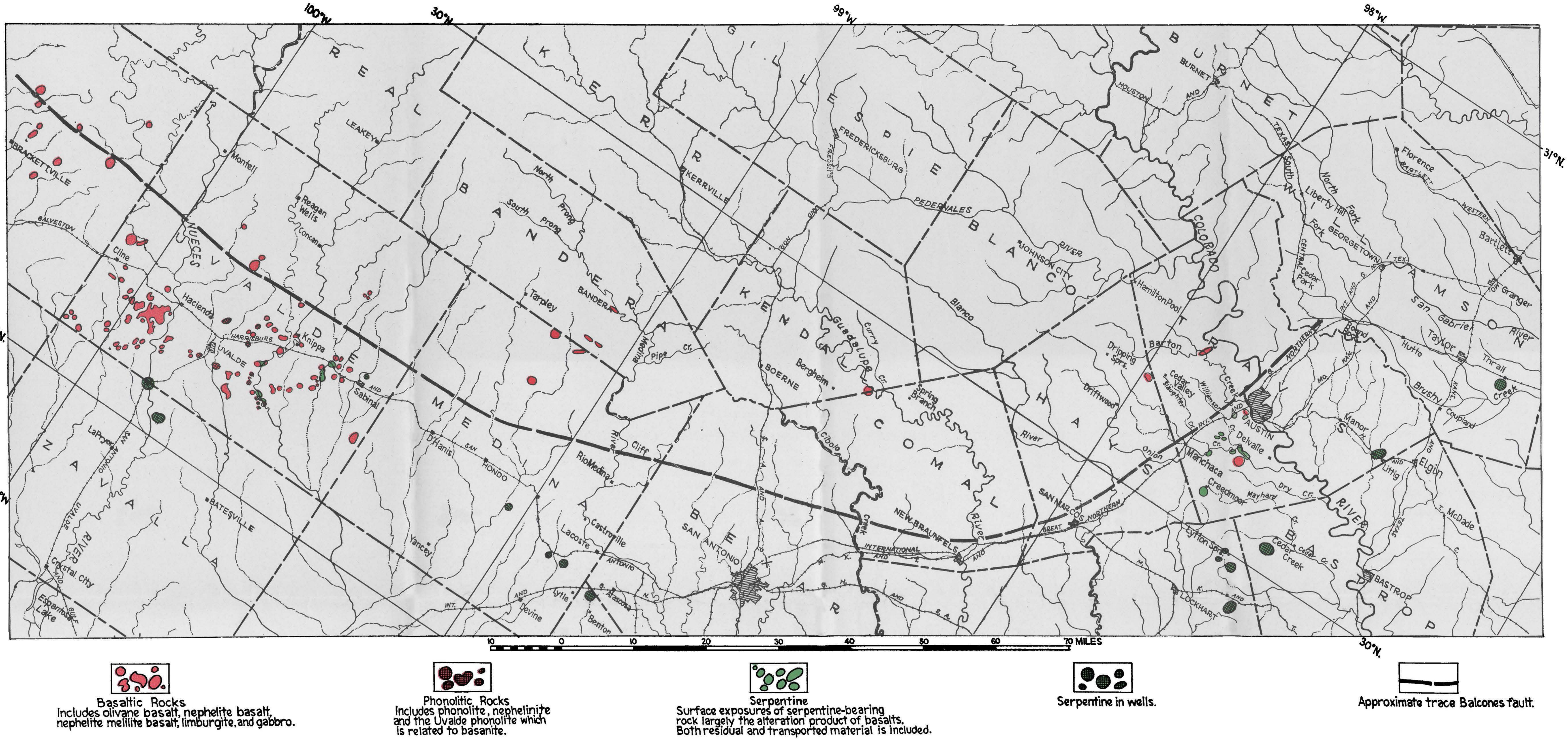

MAP SHOWING THE IGNEOUS ROCKS AND SERPENTINE OF THE BALCONES FAULT REGION OF TEXAS

By JOHN T. LONSDALE

Base adapted from U.S.G.S. State of Texas Map